Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 221 APRIL, 1936 No. 4

HIGH PRESSURE SYNTHESIS AS APPLIED TO THE MANUFACTURE OF THINGS IN EVERYDAY USE.*

BY

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The subject to be discussed is "High Pressure Synthesis," for which it is first necessary to establish a definition. What constitutes high pressure is, after all, entirely relative. What would be high pressure for one industry might be considered as a relatively low pressure by another. For this discussion it will be considered that high pressure synthesis is an operation in which a compound is synthesized from gases at a pressure of 100 atmospheres (approximately 1,500 pounds per square inch) or greater.

As illustrations of the use of high pressure synthesis in the manufacture of articles in everyday use there may be cited:

(1) Ice—obtained from central ice plants, the refrigerating machines of which are charged with ammonia, a high pressure synthesis product;

(2) Explosives—so widely used in mining of coal, of ore, quarrying of rock, and for a thousand and one uses, are based upon nitrogen compounds made from nitric acid, which in turn is made by the oxidation of ammonia, a product of high pressure synthesis;

* Presented at a meeting held Thursday, December 12, 1935.

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(3) Fertilizers—an important part of which is nitrogenous material, part of which is manufactured by high pressure synthesis;
(4) Anti-Freeze Methanol—for automobile cooling systems, a high pressure synthesis product;
(5) Automobile Finish—one of the important constituents of which is made by high pressure synthesis.

The story of high pressure synthesis must inevitably be the story of the fixation of atmospheric nitrogen, for which it was first used on a commercial scale. Nitrogen, as pointed out before, is an essential material in the fertilizer industry and in the manufacture of nitric acid which is required for explosives, dyes, plastics, etc. Nitrogen is one of our most plentiful elements—so plentiful that the atmosphere, containing as it does 79 per cent. nitrogen by volume, has over each square mile of the earth's surface 22,000,000 tons of it; or to make an illustration in more convenient terms, the site of the high pressure synthesis plant, which will be described below, has over its plant area a sufficient supply of nitrogen to operate the plant at full capacity for fifty years before it would be necessary to call upon the neighbors for any of their air. Nitrogen, however, is a very inert element and, to be of use to man, must be combined with other elements or "fixed," as it is more commonly termed.

But the story of nitrogen is also the story of Chile nitrate. Along the West Coast of South America in the Republic of Chile there is a considerable, utterly barren area which until a little over a century ago was considered to be of no value. When it was discovered that this country was overlaid with nitrate of soda and that this material was suitable for fertilizer, the chemical fertilizer industry was born. Not only was this material of value for fertilizer, but it became the source of practically all nitric acid which was produced by the treatment of nitrate of soda with sulphuric acid. The importance of this material to Chile is indicated by the fact that during the years of large nitrate production, fully one-fourth of the population was supported by and producing foodstuffs for the nitrate fields, and that an export tax of $12 per metric ton was collected by the Government, supplying approximately

30 per cent. of the Chilean Government's revenue. From the time of the development of the nitrate industry no less than $900,000,000 in export taxes was collected by that Government. When later the by-product coke oven was developed with its recovery of ammonia in the form either of aqua ammonia or of sulphate of ammonia, the world supply of chemical nitrogen was not completely dependent upon Chile nitrate. But even with this additional source, Sir William Crookes in 1898 prophesied that the Chile nitrate fields would be exhausted by 1931, at which time the world would be facing partial starvation for lack of nitrogen.

High pressure synthesis on a commercial scale really had its beginning in the World War, at the beginning of which Germany had a stock of sodium nitrate of approximately 400,000 tons, to which was added 100,000 tons upon the capture of Antwerp. The enormous amount of explosives required by the German armies could, it was presumed, be made only from nitrate of soda, and this tonnage was expected to last Germany no more than six months. When explosives continued to be used by the German armies beyond this period, it was realized that Germany had turned to other sources for nitrogen supply. It was hardly thought possible that dependence could have been placed upon the arc process, a method of fixing atmospheric nitrogen by the electric arc which had been developed on a commercial scale in Norway, but which required enormous amounts of power, nor upon cyanamide, another method of nitrogen fixation, requiring as compared with the arc process, a smaller but still large power consumption. At the conclusion of the war it was learned that Germany had developed from what was little more than a laboratory scale the Haber-Bosch high pressure synthesis process of fixing atmospheric nitrogen for the manufacture of ammonia, a scientific and industrial achievement of the first magnitude.

One of the early developments in naval warfare during the World War was the appearance of Admiral Von Spee with a small German squadron at Valparaiso. This effectively stopped shipments of nitrate of soda, prices on which rose rapidly. This was aggravated by his defeat of the small British fleet under Admiral Craddock sent to destroy him. The

presence of the German squadron in South American waters, so far from home, was by no means an accident, but was projected definitely to cut off nitrate of soda shipments so necessary to the Allies for the manufacture of explosives. England immediately sent two battle cruisers to destroy Von Spee's fleet, which was accomplished off the Faulkland Islands, after the German squadron had been driven from the Pacific by the Japanese fleet. There was thus definitely brought to all countries the importance of a nitrogen supply, independent of Chile nitrate.

By the end of the war consumption of nitrate of soda in the United States, supplying practically all of the explosives for the Allies, had risen to a rate of 2,000,000 tons per year. It will be remembered how, at that time, shipping was of desperate importance, in spite of which no less than 50 ships were required continuously to make the round trip between Chile and American ports to supply this country's nitrate of soda requirements.

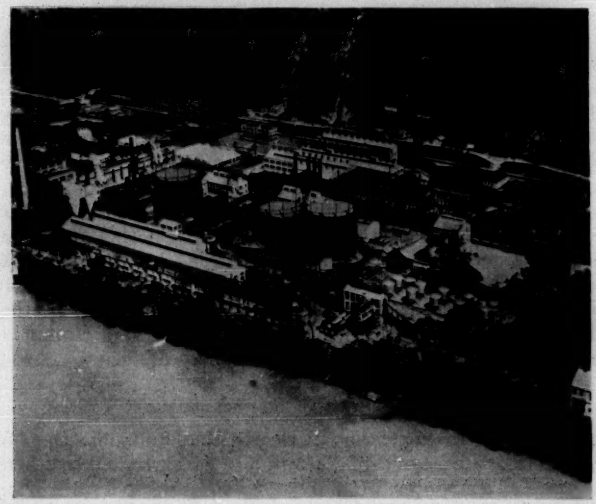
The importance of high pressure synthesis is further indicated by the fact that at the conclusion of the war one of the conditions of the Treaty of Versailles was that Germany should turn over to the Allies the plans for the high pressure synthesis plants for the fixation of nitrogen. Practically every country thereupon commenced the building of high pressure synthesis plants, which plants have been protected by subsidies, import quotas, or import duties. The United States is practically the only exception to this, the nitrogen industry here having reached its present state without any aid whatever from the Government. The first large plant here was at Muscle Shoals, which was based on the work done at a small nitrogen fixation plant of one of the large chemical companies. Unfortunately, the state of the art was such that the Muscle Shoals Plant was obsolete before it was finished and only operated enough to show that it was possible to fix atmospheric nitrogen with it. Later two very large nitrogen fixation plants were constructed here, one at Hopewell, Va., and one at Belle, near Charleston, W. Va., and then a smaller plant in California, the raw material for which is natural gas, and five plants of much smaller size utilizing by-product hydrogen, produced in the manufacture of chlorine.

The ammonia capacity of the United States can be taken now as 150,000 metric tons of nitrogen per year from by-product ammonia from coke ovens plus 300,000 metric tons from synthetic plants, a total of 450,000 metric tons of nitrogen per year—very much more than would be required for any war emergency.

THE BELLE PLANT.

Reference will frequently be made in the following discussion to the high pressure synthesis plant of E. I. duPont de Nemours & Company, located at Belle, West Virginia, some ten miles east of Charleston, the capital of the State. This plant is located on the Great Kanawha River, one of the large tributaries of the Ohio. An aeroplane photograph of the plant is shown in Fig. 1. This photograph is incomplete in

FIG. 1.



that it does not show the by-product coke ovens, which should appear at the upper left of the picture. In the lower portion is shown the bank of the Great Kanawha River, and in the

upper, the pipe lines running up the mountain for the power recovery system. Left center is the power plant, and adjoining it, the water gas plant, at the end of which is shown a saw-tooth building, the maintenance shops. The two large buildings, one in the center of the picture and the other at the lower left, are the high pressure synthesis buildings. In the lower right-hand corner is shown the experimental plant, in which there is installed a complete semi-works hydrogen production and synthesis unit. In this building have been developed on a semi-works scale, new processes and improvements to the existing processes.

The principal products made at this plant are ammonia and alcohols. Both of these operations are carried on at a pressure of approximately 700 atmospheres, which is practically 10,000 pounds per square inch. Pressures as high as 1,000 atmospheres, or 15,000 pounds per square inch have been employed.

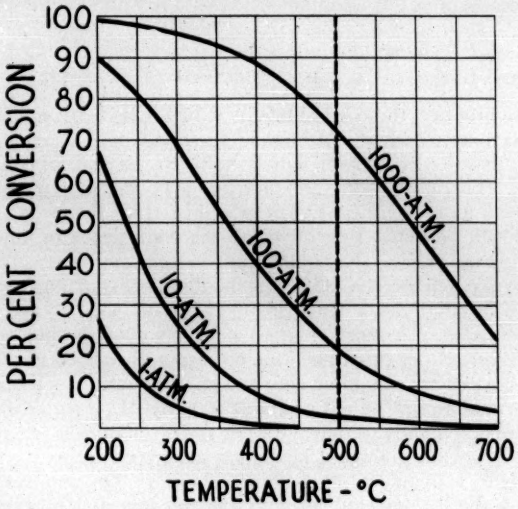
These operations were originally based upon processes developed abroad, but so many important and radical changes have been made, as a result of a vast amount of research work, that the present processes bear only an outward resemblance to the original ones. It might be noted that such a program of research and development is a necessary and expensive requirement of an operation as complicated as the production of the necessary gases of a proper standard of purity and their combination by high pressure synthesis. Without such a program, and continual improvement in the operation, it would not be possible to keep pace with the gradual but continuous lowering of selling prices which has marked the chemical industry. As an illustration, the price of ammonia is now less than half of what it was eight years ago.

WHY SYNTHESIS AT HIGH PRESSURES.

Reference to Fig. 2 shows clearly that ammonia can be synthesized at 1 atmosphere absolute pressure. Why then operate at pressures of 100 to 1,000 atmospheres? The answer is that at 1 atmosphere and at any temperature at which the reaction

$$3H_2 + H_2 = 2NH_3$$

FIG. 2.



proceeds with reasonable speed, there is practically no conversion to ammonia.

Theory indicates the advantage of pressure because 3 volumes of hydrogen and 1 volume of nitrogen upon combination produce only 2 volumes of ammonia gas. The question then becomes, what pressure? While the answer may appear rather involved, it is worthy of discussion because in the whole field of chemical manufacture there is hardly a better illustration of a balance between economic and technical factors.

Experience shows that 500° C. is about the lowest temperature at which the reaction proceeds with the desired speed. Now at this temperature it can be seen from Fig. 2 that the pressure must be of the order of 100 atmospheres or more if appreciable conversion is to be secured. In fact the fundamental advantage to be gained by operating at high pressures is illustrated by the following figures which apply to synthesis at 500° C.

Pressure, Atmospheres Absolute.	Per Cent. of Gas Converted to Ammonia at Equilibrium.	Per Cent. Ammonia in Gas after Conversion.
1	nil	nil
10	2.4	1.2
100	19.2	10.6
1,000	73.0	57.5

In practice these equilibrium values never are attained, or even approached. Actually, the maximum economy is attained when conversion is only 50 to 60 per cent. of equilibrium. Therefore, from the practical viewpoint, high pressures are even more significant than is indicated by theory.

It will be noted that owing to the contraction in volume during conversion, the equilibrium volume per cent. of ammonia is much less than the corresponding per cent. conversion of the original gas. Thus, in operation at 500° C. and 100 atmospheres, not more than 19.2 per cent. of the gas could be converted per pass, and this corresponds to 10.6 per cent. ammonia in the gas after conversion. Actually, such operation would be carried out at about 60 per cent. of equilibrium, which corresponds to only 11.5 per cent. conversion per pass, or 6.2 per cent. ammonia in the gas after conversion.

After conversion, the ammonia must be removed or "recovered" from the gas, and the unconverted portion of "residual" gas is combined with fresh gas and recycled. At pressures as high as 600 to 1,000 atmospheres, removal of ammonia is accomplished readily by simple condensation, using ordinary cooling water, but at pressures in the range 100 to 300 atmospheres, condensation by water is not feasible because too much ammonia remains in the gas phase at the cooling water temperature. Of course, condensation could be effected by refrigeration, but usually the ammonia is recovered more cheaply by scrubbing the gas with water, in which case the immediate product is strong ammonia liquor. While much of the ammonia can be used as liquor, the gas from the scrubbers is saturated with moisture which must be removed before recycling. Drying large volumes of gas necessarily is an added expense.

With higher pressures, compression costs increase, although not seriously. Since the energy required for compression is proportional to the logarithm of the absolute pressure, it can be seen that to compress gas to 1,000 atmospheres (the

upper limit of practice to date) requires in theory only a little over twice as much energy as to compress to 100 atmospheres (the lower limit of practice). Actually, there is some deviation from the theoretical energy, but not much. Also with higher pressures, the thermal problem is intensified because the exothermic heat of reaction is concentrated in a smaller volume, but these problems are not insuperable.

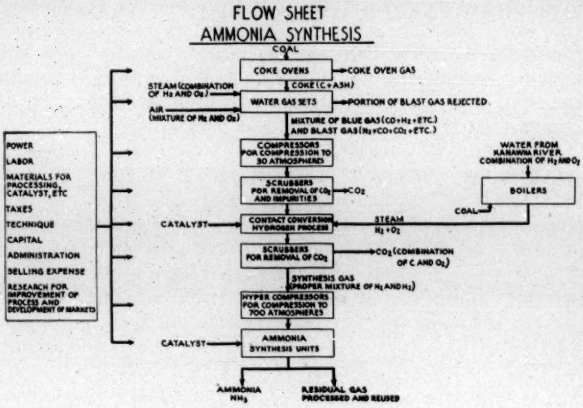
To summarize briefly the factors governing the ammonia synthesis on commercial scale, it should be borne in mind that economic considerations rule and that the general objective is the greatest possible production of ammonia per year per dollar of invested capital, consistent with operating costs. A comparison between low and high pressure operation can be boiled down to the following: At low pressures, the apparatus is low in cost per unit volume, but large in volume, whereas at high pressures the apparatus is small in volume but high in cost per unit volume. At low pressures, conversion is relatively poor. Therefore, much more unconverted gas must be recirculated than at high pressures. Likewise at low pressures, recovery by water scrubbing is costly as compared with simple condensation possible at high pressures. A disadvantage for high pressure operation is greater energy for compression. Surprising as it may seem, the various factors are sufficiently offsetting so that today we have economic operation between pressures of 100 and 1,000 atmospheres, with, perhaps, some advantage for operation in the range 700 to 1,000 atmospheres, especially if liquid ammonia is desired as the end product.

AMMONIA SYNTHESIS.

Figure 3 shows a flow sheet for the ammonia synthesis operation. This has been much simplified in order to bring out certain points, to which reference will be made further on.

Coal is coked in standard by-product coke ovens, of which the by-products are coke oven gas (used in the alcohol process), tar, benzol, toluol and xylol. It is of interest to note that ammonia is not recovered from the gas, as is usual in a by-product coke oven installation, the cost of recovery not being justified in competition with ammonia made synthetically. In other words, it pays better to burn more coal, use more

FIG. 3.



power, etc., to make ammonia, rather than to recover ammonia already present in the gas.

The coke is used as the fuel, in mechanically-clinkered water gas sets, from which is obtained a mixture of blue gas and blast gas, a portion of the blast gas being rejected through waste heat boilers. The gas mixture is now compressed to 30 atmospheres, in three-stage compressors equipped with 2,700 h.p. motors, then scrubbed for removal of carbon dioxide and other impurities, after which it enters the contact conversion hydrogen process, where, in the presence of a catalyst, the familiar chemical reaction, $CO + H_2O = H_2 + CO_2$ is carried out. The H_2O is provided as steam at a pressure of 450 pounds per square inch. Leaving the contact conversion process is a mixture of hydrogen, nitrogen and CO_2. The CO_2 is removed in scrubbers, through which is circulated a large amount of water. There now remains a gas consisting essentially of three volumes of hydrogen and one volume of nitrogen, which is the proper mixture for the synthesis of ammonia. In order to obtain just the right mixture, it is necessary to exercise precise control all the way through the process, including addition of makeup hydrogen at the proper point.

This gas is now compressed in hyper compressors driven by 2,000 h.p. motors, to a pressure of 700 atmospheres, or approximately 10,000 pounds per square inch, at which pressure it enters the ammonia synthesis converters, where, in the presence of a catalyst, and at a temperature around 500° C., the ammonia synthesis takes place. A certain amount of residual, or uncombined gas, is drawn off, processed for removal of constituents other than nitrogen and hydrogen, and returned to the system.

It is of interest to note the sources of the "raw materials" for this process. The final product, "ammonia," is a combination of nitrogen and hydrogen. The nitrogen is obtained from the inexhaustible atmosphere, entering the process with the air supplied to the water gas sets during the blast portion of the cycle. The hydrogen is obtained from an inexhaustible supply of water, the Kanawha River, being supplied to the process in the form of steam, part of which enters the process at 450 pounds pressure to the contact conversion units, and part to the water gas sets. The diagram might indicate that coal is the "raw material," but it is interesting to note that coal or carbon does not appear at all in the final product. The function of the carbon is to react with the oxygen, part of which enters the water gas sets with the air blast and part as the oxygen constituent of the steam to the hydrogen process. The carbon, therefore, leaves the process combined with oxygen, in the form of CO_2, which is removed by scrubbing, and which for the most part is wasted.

Of paramount importance in the manufacture of ammonia are such "raw materials" as shown at the left of the figure, "Power," "Labor," "Capital," "Research," etc.

The importance of "capital" can be demonstrated by the following example:

The figure usually used as the capital cost of an ammonia synthesis plant is $200 per ton of capacity per year. Amortization and depreciation can hardly be less than 7 per cent. Taxes and insurance, the other capital cost items, amount to 2 per cent. There goes on, therefore, all of the time, a capital charge of 9 per cent. of the investment, whether operating at full or part capacity. With the plant operating at full capacity this amounts to .9¢ per pound of product. The

very lowest return which must be made on such an operation, if the investment is to be justified, is 10 per cent., and even this low rate can only be justified if the plant is operated year after year at full capacity (in reality, an impossible attainment). This 10 per cent. return is an additional one cent per pound of ammonia, the total for capital charges, amortization and depreciation and return, therefore, being 1.9¢ per pound of product when the plant is operating at full capacity.

If, then, due to a depression, or failure to secure a proper amount of business, the plant operates at only 50 per cent. of capacity, the capital charges alone, without any profit, amount to 1.8¢ per pound. Furthermore, operating at lower than full capacity means an increased cost per pound of product for labor, power, overhead and other operating items. In time of poor business it is never possible to compensate for an increased manufacturing cost by increasing the selling price. The tendency, rather, is exactly the opposite. It will be seen then, that the increase in capital charges alone practically eliminates the return on the investment. In other words, an operation such as this, to be successful, must operate at all times at as great a percentage of capacity as possible. As a corollary, it is of great importance to reduce as much as possible the capital cost required for a certain output.

The necessity of maintaining full operation requires and justifies great sales effort. This must be backed up by research to maintain and widen markets. Research must also be applied continually to improvement of the process. This research cost is a heavy addition to the manufacturing cost, but is necessary, and if properly carried out, justified by the results obtained from it.

Of importance also is the development of an operating technique peculiar to processes involving high pressures and low temperatures. This technique is not something which can be obtained by reading books, but must be obtained by hard work and the expenditure of money—in the making of mistakes and overcoming them. This "charge to experience" will appear in the balance sheet in the form of heavy items to be written off to amortization and depreciation, and as high operating costs, until the difficulties are overcome.

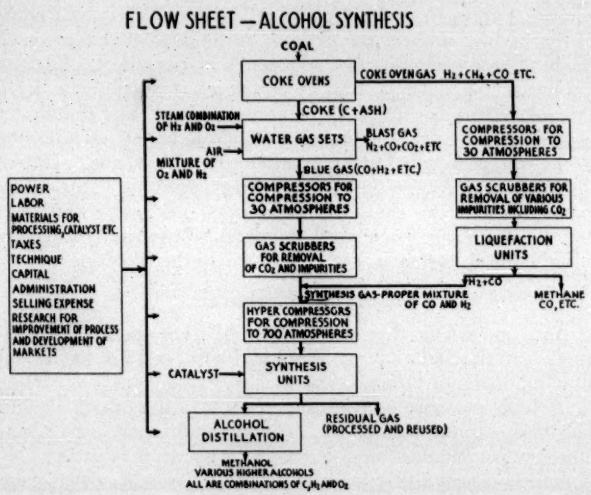
The ammonia synthesis is usually referred to as a nitrogen

fixation process. Perhaps the most important feature of the process is the manufacture of hydrogen, and so important is this that it might be more logical to refer to the high pressure synthesis of ammonia as a hydrogen fixation process rather than a nitrogen fixation process.

ALCOHOL SYNTHESIS.

In Fig. 4 is shown a flow sheet for the alcohol synthesis as conducted at Belle, West Virginia.

FIG. 4.



Coal is coked in by-product ovens, the coke being used in standard water gas sets, from which, in this process (as distinguished from the ammonia process) only the blue gas is used, all of the blast gas being rejected through waste-heat boilers. The blue gas is compressed to 30 atmospheres, scrubbed for removal of CO_2 and impurities, and to it there is then added hydrogen, which is obtained from the liquefaction of the coke oven gas. This is then the synthesis gas, the

exactly desired mixture of CO and hydrogen. It is compressed in hyper compressors to 700 atmospheres, after which it enters the synthesis units, where, in the presence of a catalyst, and at a temperature of approximately 450° C. the alcohol synthesis is carried out. The alcohol is drawn off, distilled and separated into the various fractions desired, one of the principal products being methanol, although there are various higher alcohols. A certain portion of the gas which is unconverted is processed for removal of undesired constituents and returned to the operation.

All of the products of this operation are combinations of carbon, hydrogen and oxygen. All of the carbon and some of the hydrogen enter the process in the coal, that portion of the hydrogen being distilled off as one constituent of coke oven gas in the coke ovens. This hydrogen must be separated from the coke oven gas in the liquefaction units. The remainder of the hydrogen and the oxygen come from the steam supplied to the water gas sets for the manufacture of blue gas. Unlike the ammonia process, most of the carbon entering via the coke ovens appears in the final products. Like the ammonia process, there are such very important "raw materials" as labor, capital, research, etc., as shown in the diagram.

MISCELLANEOUS COMMENTS.

In concluding this description of the operations conducted at the Belle, West Virginia Plant, certain additional facts might be of interest.

A high pressure synthesis process requires much power. The high capital cost of the process requires as nearly continuous operation as possible, and as a result, it is practicable to maintain a monthly load factor of 95 per cent. If it were practicable always to operate the plant at the same output, a yearly load factor of 95 per cent. could be maintained.

A plant such as this must have access to a large water supply—the colder the better. Water temperature is highly important because it limits compressor capacity, also the condensation or recovery of liquid ammonia from the gas after passage through the catalyst tubes. Thus during midwinter the plant capacity is from 5 per cent. to 10 per cent. greater than in midsummer, other conditions of course being

the same. It is profitable to employ refrigeration to overcome this difference.

The pumping capacity at Belle is 45,000 gallons per minute, or 65,000,000 gallons per day, sufficient at 150 gallons per capita to supply a city of 450,000 people.

The plant in employing a gas pressure as high as 1,000 atmospheres, or 15,000 pounds per square inch, uses the highest pressure employed in industry, whether operating on gas or liquid. At this pressure the compressed gas, while still a gas, acts very much as a liquid. It has, as a matter of fact, approximately one-fifth the density of water, whereas, before compression its density was only 30 per cent. of the density of air. One interesting feature is that at this density, in the high pressure cylinders of the compressor, it is of little value to attempt to cut down the clearance space as any reasonable increase in clearance space does not reduce the capacity of the cylinder, as is the case with compressed gas at usual pressures.

Further regarding handling gases at high pressure, it might be pointed out that the so-called "perfect" gas laws are by no means perfect. For example, at 1,000 atmospheres, and at the temperature of final compression, the hydrogen-nitrogen synthesis gas occupies a volume nearly twice as great as is indicated by the gas laws. This and other deviations from theory are of course extremely important, especially to the design engineer. Since the published or handbook data covering the behavior of gases at high pressures are inadequate, the chemist or engineer must, as a matter of course, secure his own data, particularly in the fields of heat transfer, fluid flow, strength of materials, and metallic corrosion. We, therefore, have the rather curious aspect of "fundamental" research carried on in a plant side by side with research of the well-known "pipe-wrench" and "wash-tub" variety. It is all in the day's work.

The plant employs great extremes of temperature. In the water gas sets a temperature of 2,400° F. is reached, and in the liquefaction process, a temperature of 350° F. below zero, a range of 2,750 Fahrenheit degrees.

The time required to go from raw material, coke, to finished product, ammonia or alcohols, is very short, only 30 minutes. The amount of gas to be handled is so very large

that storage of more than a few minutes' supply is not practicable. There is thus very little material in process. This does not mean that the process does not require a large fund of working capital. Much is required for finished product, catalyst, repair materials, etc.

To illustrate the magnitude of gas volumes required in Belle Plant operations, it might be noted that the water gas capacity alone is sufficient to supply the requirements of a city of 2,000,000 population.

A plant such as this requires a large capital expenditure for instruments and control devices—at the Belle Plant, over $500,000. One necessity for this is the absence of intermediate storage of appreciable size. In a plant where such intermediate storage could be provided, one operation could go wrong without affecting the rest of the plant. With only a few minutes' storage, however, every operation must go right at all times or else the entire plant shuts down.

The process well illustrates the difference between a mechanical and a chemical process. In a mechanical process, say the manufacture of an automobile, the workmen are busy fabricating and assembling various parts, literally a total of thousands of detailed operations. Within limits, the busier the men, the greater the efficiency of the operation. In a chemical process, such as the synthesis of ammonia and alcohols, equipment is provided to carry out a certain operation. Mechanically, the process is most efficient when the workmen are doing nothing, that is, when they are simply standing around watching the apparatus operate properly. When workmen are busy, it is because something has gone wrong involving maintenance cost. Maintenance being one of the large cost items in high pressure synthesis, this might be put another way: a machine operating is not only producing product for sale, but it is not requiring maintenance.

THE INFLUENCE OF JAMES WATT ON THE CENTRAL STATION INDUSTRY.*

BY

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With the conception and installation of the Pearl Street Station in September 1882 in New York, the Electric Light and Power Industry became a fact and from such small beginnings a mighty industry has developed. A few weeks later the Appleton, Wisconsin, plant was started. The Appleton generators were driven by a waterwheel and its successors using the same prime mover dominate about one-third of the central station industry. But Mr. Edison with a conception of a universal system of light and power supply saw, with clear vision, the possibilities of the steam engine as a prime mover and located his generating stations as nearly as possible in the center of distribution. Flexibility, continuity, availability at all times and independent of weather or rainfall, or the presence of flowing water, he chose and adopted for his purposes the steam engine which Newcomen had invented and James Watt had perfected and adapted to the transmission of power through a rotating shaft.

This prime mover which Watt at the beginning of the nineteenth century had left practically complete (the only major improvement since that time being the Corliss Valve), held sway for a full century as the only independent source of power that could be located anywhere and it was on Watt's inventions that the central station industry was built up and spread to the uttermost ends of the earth.

One of the six major inventions or discoveries of Watt was a knowledge of the expansive force of steam. The application of this principle made the steam engine an economical source of power and as the years rolled by this prin-

* Address delivered at the dinner held under the auspices of The Franklin Institute on the occasion of the observance of the Two Hundredth Anniversary of the birth of James Watt, Tuesday, January 21, 1936.

ciple became the base of a system of power generation which has replaced to a large extent Watt's reciprocating engine by a fluid velocity engine, the steam turbine. The 35 years of this century have seen the development of this new prime mover to enormous size, 225,000 of Watt's horsepowers in a single unit and to a volume exceeding 150,000,000 horsepower. This development may be partly attributed to Watt who made clear to all men the principle of the expansive force of steam.

Watt's career was based on experimentation. What he did not know he immediately tried, working continuously from failure to success and Edison and the Central Station Industry have built their successes on the same principle. From its earliest beginnings the central station industry has never been content to take things as they are; witness Edison in 1881 starting Wheeler on a model of his distribution system to actually find out what was needed in copper and thus doing what Watt did with his steam jacket and separate condenser. From this model, Edison gained facts which leading to further experimentation gave him the idea of the three wire system which saved 65 per cent. of the copper investment in distribution systems. Edison hunted for a means to measure the electric current so he gave us the chemical meter and other inventors followed with the indicating and recording instruments, following Watt's lead in finding a measure for power and producing the engine indicator. Only a day or two ago, the air has been full of a report by President Compton of the Massachusetts Institute of Technology on a National Research Problem similar to Watt's work from 1765 to 1785 on his prime mover. We perhaps do not consciously look back to the Glasgow University instrument maker but the whole central station industry is emulating his example and applying experimental knowledge to the improvement in every possible way of central station service.

Playfair, a contemporary of Watt, is quoted by Stuart more than 100 years ago as follows:

"It would be difficult to estimate the value of the benefits which these inventions have conferred upon the country. There is no branch of industry that has not been indebted to them, and in all the most material they have not only widened,

most magnificently, the field of its exertions, but multiplied a thousand fold the amount of its productions. . . . It has armed the feeble hand of man, in short, with a power to which no limits can be assigned, completed the dominion of mind over matter, and laid a sure foundation for all those future miracles of mechanic power which are to aid and reward the labour of after generations."

We who are gathered here tonight, two hundred years after the birth of James Watt and one hundred years after this appreciation of Watt's solution of the power problem, may wonder at the clear vision, the breadth of view, which could prophesy so truly the triumphs of our Power Civilization.

Hershey's New Windowless Office Building.—(*Buildings and Building Management*, Dec. 1935.) In order to house its executive and clerical departments, including its printing plant, the Hershey Chocolate Plant in Hershey, Pa., is constructing this building, not as an experimental stunt but with the firm belief that the artificially produced working conditions inside the structure will be superior to conditions in an ordinary building. The structure is 151 ft. wide and 308 ft. long, 3 stories high at one end and 2 at the other. The walls are of stone and the roof consists of a dead level concrete deck designed to store 2½ inches of water over its whole surface, to be fed by rainfall. Although the inside of the building should be effectively insulated from exterior noises, the windowless construction makes the problem of interior echoes more important than ever. Acoustical treatment is being given to most of the office and office space corridor ceilings. An acoustic cork tile 1½ inches thick was the product selected. An air conditioning system is designed to control temperatures and humidity automatically regardless of the season. It is estimated that heating and cooling costs can be reduced 25 per cent. by eliminating heat leakage occurring in buildings with windows. A novel mechanism informs the occupants what kind of weather to expect outside as they leave the building. For illumination, an effect of actual daylight without its accompanying eye-strain will be achieved by the use of special fixtures which combine the most desirable features of the Mazda and the mercury vapor lighting systems. The lighting will be almost completely indirect and the fixtures are so installed that an intensity of 20 foot candles will be constantly maintained at the working level, on the desks. Better working conditions and less operating cost are the two principal objects sought for.

R. H. O.

AN OPERATIONAL PROOF OF THE WAVE-POTENTIAL THEOREM, WITH APPLICATIONS TO ELECTRO-MAGNETIC AND ACOUSTIC SYSTEMS.

BY

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In the theory of the ordinary potential the fundamental problem is that of finding the potential of a known distribution of sources, with given boundary conditions. We have to solve the equation:

$$\nabla^2 u = F(x, y, z)$$

subject to the boundary conditions. The following integral solution is obtained:

$$u = -\frac{1}{4\pi}\int\int\int \frac{F}{r}\,dv + \frac{1}{4\pi}\int\int\left[\frac{1}{r}\frac{\partial u}{\partial n} - u\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\right]dS, \quad (2)$$

where the values of u and $\partial u/\partial n$ are those at the boundary of the region of volume integration.

Corresponding to this fundamental problem in the Newtonian potential theory, we have an analogous problem in the case of the wave-potential, when the sources vary with time: given the distribution of sources and the boundary conditions, to find the wave-potential. We have to solve the wave equation:

$$\nabla^2 u - \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} = F(x, y, z, t) \quad (3)$$

subject to the boundary conditions. An integral solution is:

$$u = -\frac{1}{4\pi}\int\int\int \frac{[F]}{r}\,dv + \frac{1}{4\pi}\int\int\left\{\frac{1}{r}\left[\frac{\partial u}{\partial n}\right] + \frac{1}{cr}\frac{\partial r}{\partial n}\left[\frac{\partial u}{\partial t}\right] - [u]\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\right\}dS, \quad (4)$$

where the symbol $[x]$ signifies that the value of the quantity is to be taken at the time $t - r/c$ (i.e. retarded), where r is

the distance between the observation point and the integration element.

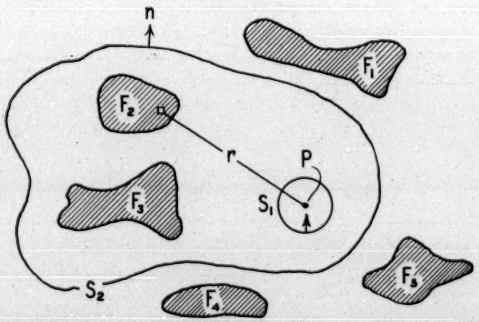
This solution was given by Kirchoff [1] and the surface integral is generally accepted as the mathematical justification of Huygen's principle. A modern proof of this theorem has been given by Mason.[2] The following demonstration,[3] by means of the operational calculus, may be of interest in view of its comparative simplicity and as a particularly good illustration of the power and convenience of the symbolic method. As is usual in applications of this calculus, the argument may be regarded more as a demonstration than as a rigorous proof in the formal sense.

In addition to the proof some applications of the wave potential theorem to the electromagnetic and acoustic equations will be given. The conventional use of a simplified and modified theorem in the textbooks on acoustics will be critically reviewed and shown to be erroneous.

PROOF.

Consider a space (Fig. 1) containing a distribution of sources F_1, F_2, $\cdots$, and in particular a region of this space

FIG. 1.



[1] G. Kirchoff, *Berliner Sitzungber.*, 641 (1882): H. Bateman: "Electrical and Optical Wave Motion," p. 147 (Cambridge, 1915).

[2] Max Mason, *Phys. Rev.*, 15, 312 (1920).

[3] This proof was originally appended to a report to the Bureau of Engineering, Navy Department, entitled "Effect of Asymmetrical Radiation from the Transmitting Antenna on the Calibration of Radio Compasses," June 15, 1921.

contained between the surface S_2 and a small sphere S_1 surrounding the observation point P. Following the notation of Kneser we denote by $f(1)$ the value of a quantity at the observation point P and by $f(0)$ its value in the integration element. Let r denote the distance between these points.

In applying the operational method we replace the time differential d/dt by the symbol p which we regard purely as an operator subject to the ordinary rules and manipulations of algebra.[4] The wave equation (3) then takes the form:

$$\nabla^2 u + \frac{p^2}{c^2} u = F(x, y, z, t). \tag{5}$$

Applying Green's theorem to the region between the surfaces S_1 and S_2, using outward normals, as shown in Fig. 1, we have:

$$\iiint [\psi \nabla^2 \varphi - \varphi \nabla^2 \psi] dv = \iint \left[\psi \frac{\partial \varphi}{\partial n_2} - \varphi \frac{\partial \psi}{\partial n_2} \right] dS_2 - \iint [\text{“}] dS_1. \tag{6}$$

Now let $u = \varphi$ be a solution of (5) finite and continuous, together with its first derivative, etc., in R. Let ψ represent the appropriate Green's Function, a solution of:

$$\nabla^2 \psi + p^2 \psi / c^2 = 0. \tag{7}$$

A suitable function is:

$$\psi \equiv G(0, 1) = e^{-pr/c}/r. \tag{8}$$

Consider the integral over the small sphere S_1. Allow the radius, ϵ, to decrease; then in the limit since $dS = \epsilon^2 d\omega$, where ω is the solid angle

$$\lim_{\epsilon \to 0} \iint \left[u \frac{\partial}{\partial n} \left(\frac{e^{-pr/c}}{r} \right) - \frac{e^{-pr/c}}{\epsilon} \frac{\partial u}{\partial n} \right] \epsilon^2 d\omega = -4\pi u(1), \tag{9}$$

since u remains finite and $\epsilon \exp(-p\epsilon/c)$ approaches zero; and

[4] A. R. Forsyth, "Treatise on Differential Equations," p. 57 (MacMillan, 1914).

$\lim (\epsilon \to 0) \partial/\partial n (\exp - pr/c)/r = 1/r^2$, etc. Hence we have finally, making the above substitution in (6),

$$u(1) = -\frac{1}{4\pi}\int\int\int \frac{e^{-pr/c}}{r} F(0)dv + \frac{1}{4\pi}\int\int \left\{ \frac{e^{-pr/c}}{r}\frac{\partial u}{\partial n} - u\frac{\partial}{\partial n}\left(\frac{e^{-pr/c}}{r}\right)\right\} dS_2. \quad (10)$$

This result is merely formal; it remains to interpret the action of the operator $e^{-pr/c}$ upon a function $f(x)$. This is Heaviside's "shift operator" [5] and occurs in the symbolic expression of Taylor's theorem:

$$\begin{aligned} e^{-pa}\cdot f(x) &= \left[1 - pa + \frac{1}{2}(pa)^2 + \cdots\right] f(x) \\ &= f(x) - \frac{\partial f}{\partial x}a + \frac{1}{2}\frac{\partial^2 f}{\partial x^2}a^2 + \cdots \\ &= f(x-a), \end{aligned} \quad (11)$$

and has the result in the present case of "retarding" all the quantities upon which it operates, that is to say:

$$e^{-pr/c} f(t) = f\left(t - \frac{r}{c}\right) = [f]. \quad (12)$$

The designation $[f]$ will be employed to denote the quantities so retarded, whose values are to be taken at the time $t - r/c$.

Consider the surface integral in (10). Carrying out the differentiations:

$$u\left[\frac{\partial}{\partial n}\left(\frac{e^{-pr/c}}{r}\right)\right] = -\frac{1}{rc}\frac{\partial r}{\partial n}\left[\frac{\partial u}{\partial t}\right] + [u]\frac{\partial}{\partial n}\left(\frac{1}{r}\right) \quad (13)$$

and

$$-\frac{\partial u}{\partial n}\frac{e^{-pr/c}}{r} = -\frac{1}{r}\left[\frac{\partial u}{\partial n}\right], \quad (14)$$

so that after algebrization (10) becomes finally:

$$u(1) = -\frac{1}{4\pi}\int\int\int \frac{[F]}{r}dv + \frac{1}{4\pi}\int\int \left\{ \frac{1}{r}\left[\frac{\partial u}{\partial n}\right] + \frac{1}{rc}\frac{\partial r}{\partial n}\left[\frac{\partial u}{\partial t}\right] - [u]\frac{\partial}{\partial n}\left(\frac{1}{r}\right)\right\} dS. \quad (15)$$

[5] For a discussion of this operator see Heaviside, "Electro-Magnetic Theory," Vol. 2, p. 110; Vol. 3, p. 234.

This represents the value of u at an observation point 1 in terms of a volume integral over all the sources within the region R, and a surface integral over S_2 which represents the effects of all sources outside of S_2. The effect of any source within R may be expressed equivalently by volume integration or by an integral over a surface enclosing it. Point 1 may be outside this surface. All values under the integral signs are to be taken at the integration element.

It may be noted in passing that $e^{pr/c}$ (with positive exponent) is also a solution of (5) and presumably may be used as a Green's Function. The effect of this operator is to "accelerate" all quantities upon which it operates so that the values are to be taken at the later time $t + r/c$. The bracketted terms in (15) are all accelerated and the sign of the second term in the surface integral is reversed. It can be shown that this gives a proper solution, at least formally.[6] The physical interpretation is not, however, quite so clear, particularly in terms of Huygen's wavelets, since the disturbance at the observation point is expressed in terms of what takes place at the integration element *in the future* rather than in the past. The elementary waves collapse on the sources instead of proceeding from them. Such a physical picture is, of course, inconsistent with our ordinary ideas of causality.

APPLICATION TO THE ELECTROMAGNETIC WAVE EQUATIONS.

An important application of this wave-potential theorem may be made to the solution of the electromagnetic wave equations, which may be written in Gaussian units:

$$\nabla^2 E - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = 4\pi\left[\text{Grad } \rho + \frac{1}{c^2}\frac{\partial}{\partial t}(\rho v)\right], \qquad (16)$$

$$\nabla^2 H - \frac{1}{c^2}\frac{\partial^2 H}{\partial t^2} = -4\pi \text{ Curl } (\rho v), \qquad (17)$$

where ρ is the density of charge, and ρv the current, both

[6] An example of the use of the acceleration operator in a particular problem will be given later in connection with equation (55).

distributions being assumed given. Applying (15) we have the solutions:

$$E(1) = -\iiint \frac{1}{r}[\mathrm{Grad}_0\,\rho]dv - \frac{1}{c^2}\iiint \frac{1}{r}\frac{\partial}{\partial t}[\rho v]dv + \text{surface integral}, \quad (18)$$

$$H(1) = \frac{1}{c}\iiint \frac{1}{r}[\mathrm{Curl}_0\,(\rho v)]dv + \text{surface integral}. \quad (19)$$

The subscript o denotes that the differentiations are to be performed at the integration element.

If it be desired to transfer the operation at the integration element to one at the observation point we may proceed as follows, keeping constantly in mind the retarded nature of the bracketted quantities.

Consider the first integral in (18). For convenience let $D = e^{-pr/c}$. Then:

$$\frac{1}{r}[\mathrm{Grad}_0\,\rho] = \frac{D}{r}\mathrm{Grad}_0\,\rho \quad (20)$$

$$= \mathrm{Grad}_0\left(\frac{D\rho}{r}\right) - \rho\,\mathrm{Grad}_0\left(\frac{D}{r}\right). \quad (21)$$

Now

$$\mathrm{Grad}_0\,(D/r) = -\mathrm{Grad}_1\,(D/r), \quad (22)$$

hence:

$$\iiint \frac{D}{r}\mathrm{Grad}_0\,\rho\,dv = \iiint \mathrm{Grad}_0\left(\frac{D\rho}{r}\right)dv + \iiint \rho\,\mathrm{Grad}_1\left(\frac{D}{r}\right)dv. \quad (23)$$

Transform the first volume integral into a surface integral by means of the theorem:

$$\iiint \mathrm{Grad}\left(\frac{D\rho}{r}\right)dv = \iint \frac{D\rho}{r}\cdot n\,dS, \quad (24)$$

where n is a unit vector normal to the surface of integration.

$$\iiint \frac{1}{r}[\mathrm{Grad}_0\,\rho]\,dv = \iiint \mathrm{Grad}_1\frac{[\rho]}{r}dv + \iint \frac{[\rho]}{r}\cdot n\,dS. \quad (25)$$

If the surface of integration does not cut through any charges, the surface integral in (25) vanishes. We have then:

$$E(1) = -\operatorname{Grad}_1 \iiint \frac{[\rho]}{r} dv - \frac{1}{c^2} \iiint \frac{[\rho v]}{r} dv + \text{surf. int.} \quad (26)$$

Similarly the volume integral in (19) can be transferred to one involving an operation at the observation point. Letting $I = \rho v$

$$\frac{D}{r} \operatorname{Curl}_0 I = \operatorname{Curl}_0 \left(\frac{DI}{r} \right) + I \times \operatorname{Grad}_0 \left(\frac{D}{r} \right) \quad (27)$$

and

$$I \times \operatorname{Grad}_0 \left(\frac{D}{r} \right) = \operatorname{Curl}_1 \left(\frac{DI}{r} \right) \quad (28)$$

in view of the nature of the differentiation. Hence:

$$\iiint \frac{D}{r} \operatorname{Curl}_0 I \, dv = \iiint \operatorname{Curl}_0 \left(\frac{DI}{r} \right) dv + \iiint \operatorname{Curl}_1 \left(\frac{ID}{r} \right) dv. \quad (29)$$

Transform the first volume integral on the right side by means of the relation:

$$\iiint \operatorname{Curl} A \cdot dv = \iint (n \times A) dS. \quad (30)$$

Then

$$\iiint \frac{1}{r} [\operatorname{Curl}_0 I] dv = \operatorname{Curl}_1 \iiint \frac{[\rho v]}{r} dv + \iint \frac{(n \times I)}{r} dS. \quad (31)$$

If the surface does not cut any current, the surface integral vanishes, leaving:

$$H(1) = \frac{1}{c} \operatorname{Curl}_1 \iiint \frac{[\rho v]}{r} dv + \text{surf. int.} \quad (32)$$

If as a special case we allow the surface S_2 to recede to infinity

so that the region includes all charges and currents, all the surface integrals in (26) and (32) vanish leaving special expressions for E and H which will be recognized as those given by the classical electron theory in terms of the retarded vector and scalar potentials.

APPLICATIONS TO ACOUSTICS.

The fundamental equations for sound waves in an inviscid gaseous medium can be written in the following forms. Let p = excess or acoustical pressure, v = velocity, P_0 = ambient pressure, γ the ratio of the specific heats of the medium, ρ the density.

Euler's equation of motion in response to an applied vector force F:

$$\frac{\partial v}{\partial t} + \frac{1}{2}\operatorname{Grad} v^2 - v \times \operatorname{Curl} v + \frac{1}{\rho}\operatorname{Grad} p = F. \tag{33}$$

For irrotational motion, $Curl\, v = o$. The equation of continuity:

$$\frac{\partial \rho}{\partial t} + \rho \operatorname{Div} v + v \operatorname{Grad} \rho = 0. \tag{34}$$

For adiabatic expansion of the gas:

$$p = a^2 \rho^{\gamma}. \tag{35}$$

Neglecting higher order terms, for waves of small amplitude, and eliminating between these equations we find that p and v satisfy the wave equations:

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = \rho \operatorname{Div} F, \tag{36}$$

$$\nabla^2 v - \frac{1}{c^2}\frac{\partial^2 v}{\partial t^2} = -\frac{1}{c^2}\frac{\partial F}{\partial t}, \tag{37}$$

where c is the velocity of sound $= (\gamma P_0/\rho)^{1/2}$. Denote by φ the *velocity-potential* from which p and v may be derived as follows:

$$P = \rho \partial \varphi / \partial t, \tag{38}$$

$$v = -\operatorname{Grad} \varphi. \tag{39}$$

φ also satisfies the wave equation.

The wave-potential theorem (15) can be applied directly to (36), (37) or to find φ. If there are no volume sources ($F = 0$) throughout the region R the calculation is reduced to a surface integration. In the case of the velocity-potential φ, for example:

$$\varphi = \frac{1}{4\pi}\int\int\left\{\frac{1}{r}\left[\frac{\partial\varphi}{\partial n}\right] + \frac{1}{cr}\frac{\partial r}{\partial n}\left[\frac{\partial\varphi}{\partial t}\right] + \frac{[\varphi]}{r}\frac{\partial r}{\partial n}\right\} dS. \quad (40)$$

A case of special interest occurs when φ varies sinusoidally with time, or φ is proportional to $e^{i\omega t}$. In this case, if $k = \omega/c$:

$$\varphi = \frac{e^{i\omega t}}{4\pi}\int\int\left\{\frac{e^{-ikr}}{r}\frac{\partial\varphi}{\partial n} - \varphi\frac{\partial}{\partial n}\left(\frac{e^{-ikr}}{r}\right)\right\} dS. \quad (41)$$

φ is thus given in terms of φ and $\partial\varphi/\partial n$ over the boundary.

As a simple check on the application of this formula consider the case of a plane wave advancing along the x axis in which $\varphi = e^{i\omega t}e^{-ikx}$. We wish to calculate the value of φ at $x = 0$ by means of (41). To simplify the integration we choose a spherical surface of integration; r, the radius of the sphere, is then a constant. The area of a belt-like surface element bounded by planes through x and $x + dx$ is $dS = 2\pi r dx$ and we integrate between $-r$ and $+r$. Omitting details:

$$\frac{1}{4\pi}\int\int\frac{e^{-ikr}}{r}\frac{\partial\varphi}{\partial n}dS = \frac{e^{i\omega t}}{2ikr}[e^{-2ikr}(1 + ikr) - (1 - ikr)], \quad (42)$$

$$\frac{1}{4\pi}\int\int\varphi\frac{\partial}{\partial n}\left(\frac{e^{-ikr}}{r}\right)dS = -\frac{e^{i\omega t}(1 + ikr)}{2ikr}[e^{-2ikr} - 1]. \quad (43)$$

The sum of these terms gives $e^{i\omega t}$ which is the correct value of φ at $x = 0$.

A simple *surface source* in acoustics, analogous to a surface charge in electrostatics, is defined as one in which there is an equal efflux and influx of fluid on each side of the surface. The pressure (or φ) is continuous in crossing such a surface source but there is a discontinuity in the normal component of velocity, $\partial\varphi/\partial n$, which measures the strength of the surface source. Suppose we desire to compute the disturbance at a point P due to such a source (which we suppose to vary

sinusoidally). Surround the surface source by a closely fitting surface of integration and apply (41). Since φ is continuous in crossing the surface the second term in (41) vanishes over the two sides. In the first term the integral over one side is equal to that over the other by the definition of the source, hence:

$$\varphi = \frac{1}{2\pi}\int\int \frac{\partial \varphi}{\partial n}\frac{e^{-ikr}}{r}\,dS, \tag{44}$$

the integration being extended over the open surface. This result was stated by Rayleigh (*Theory of Sound*, Vol. II, p. 95, 1878). Its significance is limited to the calculation of surface sources when $\partial\varphi/\partial n$ is discontinuous and φ is continuous on some bounded surface. A physical embodiment of such a source would be two infinitely thin surfaces infinitely close together vibrating in opposition.

A *double surface source* is characterized by a discontinuity in φ and continuity of $\partial\varphi/\partial n$ in crossing the surface. In this case the first term in (41) vanishes and:

$$\varphi = \frac{1}{2\pi}\int\int \varphi \frac{\partial}{\partial n}\left(\frac{e^{-ikr}}{r}\right) dS, \tag{45}$$

a result also stated by Rayleigh (*loc. cit.*, p. 97). A physical embodiment of such a source would be an infinitely thin vibrating surface actuated by mechanical forces. On one side the pressure would be positive and on the other side negative.

It should be emphasized that the validity of theorems (44) and (45) is limited to surfaces of discontinuity, that is, to surface sources. This restriction does not, however, seem to have been recognized in the literature of acoustics, where these theorems (44) and (45) are commonly misapplied and endowed with a generality which they do not possess. Such misapplications pervade the entire literature; they are to be found in the classical works and have been copied into all of the textbooks on the subject. The following example is typical. Lamb ("Dynamical Theory of Sound," p. 253) attempts to calculate the value of φ for a plane wave by means of (45), integrating over an infinitely extensive plane wave front. In the first place such a surface of integration is

improper since it does not completely enclose the observation point. The surface of integration should also include the infinite sphere or its equivalent because the wave train is assumed to be infinite and φ does not therefore vanish at infinity. Also there is no discontinuity in φ in such a wave field, nor in $\partial\varphi/\partial n$; the use of (45) is therefore unjustified. Just why (45) was chosen rather than (44) is not stated. As a matter of fact (44) does not converge over the infinite surface of integration, but (45) does. This accidental but wholly irrelevant circumstance may have dictated the choice. In any event a proper calculation in this case consists in the use of the complete wave-potential theorem (41), which includes both (44) and (45), and for an infinite wave train the integration must extend over an enclosing surface. We can, however, omit the integration over the infinite sphere and confine the integration to a finite part of the plane wave front by postulating a *limited* train of waves as follows.

Let it be assumed that the sinusoidal wave train has existed for an epoch T prior to the time t. Let x represent the distance of the observation point from the plane wave surface at $x = 0$. Then $r^2 = x^2 + a^2$; $dS = 2\pi a da = 2\pi r dr$. Integrate with respect to r between R and x. The upper limit R is the value of r corresponding to the time T, i.e. $R = cT$. For $r > R$ the integral vanishes because the wave did not exist prior to $t - T$. We will assume that the time variation is a sine function and that the wave started from zero amplitude. This avoids discontinuities in the time derivatives and improper integrals. Applying (41) we have:

$$\frac{1}{4\pi}\int\int \frac{\partial\varphi}{\partial n}\frac{e^{-ikr}}{r}dr = \frac{ik}{2}\int_x^R e^{-ikr}dr = -\frac{1}{2}\left[e^{-ikr} - e^{-ikx}\right], \quad (46)$$

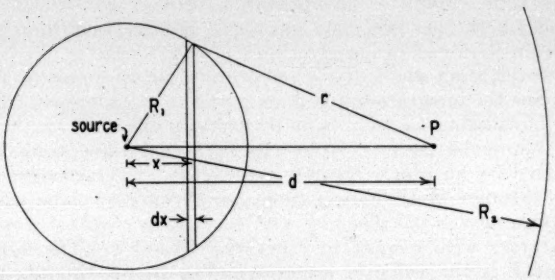
$$\frac{1}{4\pi}\int\int \varphi\frac{\partial}{\partial r}\left(\frac{e^{-ikr}}{r}\right)dr = -\frac{1}{2}\left[\frac{x}{R}e^{-ikR} - e^{-ikx}\right]. \quad (47)$$

Now $e^{-ikR} = 0$ because we postulated a wave train starting at 0 (sine function) so that the sum of the two terms gives $\varphi = e^{-ikx}$, a correct result. Note that (46) gives one-half the value that we should have obtained by applying (44) alone, and (47) gives one-half the value of (45). The two terms contribute equal amounts.

In connection with the calculation of the disturbance at a point due to a plane wave it may be noticed that if we had followed the classical procedures and had used (44) in our previous calculation (eqs. 42 and 43) we should have gotten an expression equivalent to eq. (42) multiplied by 2; and if we had used (45) we should have obtained (43) multiplied by 2. Obviously either result is erroneous.

Another interesting example of the failure of the classical theorems in the general case is provided by the following calculation. With reference to Fig. 2 let it be desired to

FIG. 2.



calculate the velocity-potential at P due to the spherical wave emanating from a point source at $x = 0$. Let r' represent the radial distance from this source. Then φ will be assumed to be of the form:

$$\varphi = e^{i\omega t}e^{-ikr'}/r'.$$

For simplicity we shall omit the time factor $e^{i\omega t}$, and choose as surfaces of integration enclosing the space a sphere of radius R_1 surrounding the source, and a sphere of radius R_2 surrounding the source and observation point. The value of r will be constant over a belt-like integration element normal to the x-axis of elementary area; $dS = 2\pi R dx = 2\pi R dr/d$. Also:

$$r^2 = R^2 + d^2 - 2Rd\cos\theta \tag{48}$$

and

$$\frac{\partial}{\partial n}\left(\frac{e^{-ikr}}{r}\right) = \frac{R^2 - d^2 + r^2}{2rR}\frac{\partial}{\partial r}\left(\frac{e^{-ikr}}{r}\right). \tag{49}$$

$\partial\varphi/\partial n$ and φ are both constant over the sphere and have the values

$$\frac{\partial\varphi}{\partial n} = -\frac{(1+ikR)}{R^2}e^{-ikR}; \qquad \varphi = e^{-ikR}/R. \tag{50}$$

For the two terms in (41) we have then:

$$\frac{1}{4\pi}\int\int\frac{\partial\varphi}{\partial n}\frac{e^{-ikr}}{r}\,dS = \frac{R_1}{2d}\frac{\partial\varphi}{\partial n}\int_{d-R_1}^{d+R_1} e^{-ikr}\,dr$$

$$= -\frac{e^{-ikd}}{d}\,\frac{e^{-ikR_1}(1+ikR_1)}{2ikR_1}\left[e^{-ikR_1} - e^{ikR_1}\right] \tag{51}$$

and

$$-\frac{1}{4\pi}\int\int\varphi\,\frac{\partial}{\partial n}\left(\frac{e^{-ikr}}{r}\right)dS$$

$$= \frac{e^{-ikd}}{d}\,\frac{e^{-ikR_1}}{2}\left[e^{-ikR_1} + e^{ikR_1} + \frac{1}{ikR_1}\left(e^{-ikR_1} - e^{ikR_1}\right)\right]. \tag{52}$$

The sum of these terms equals $\varphi = e^{-ikd}/d$. As to the integral over the outer sphere, if we consider a finite train of waves of duration T we can let the radius of the outer sphere increase until $R > cT$; then φ and $\partial\varphi/\partial n = 0$ on the sphere and this integral vanishes. This also vanishes in the case of an infinite train of waves as can be shown by carrying out the integration. We arrive therefore at the correct result $\varphi = e^{-ikd}/d$. The use of (44) or (45) would have led to the erroneous results expressed by (51) or (52) respectively.

The case of a spherical wave converging on the point $r' = 0$ is interesting. In this case $\varphi = e^{ikr'}/r'$ and the integral over the outer sphere yields the value

$$\varphi = \frac{e^{ikd}}{d} - \frac{e^{-ikd}}{d}. \tag{53}$$

The integral over the inner sphere yields

$$\varphi = \frac{e^{-ikd}}{d} \tag{54}$$

and the sum gives the correct result e^{ikd}/d. This may be interpreted as follows. The convergent wave is reflected at the sink-point singularity $r' = 0$ and again diverges, the

resultant field being expressed by the sum of the two waves as in (53). In order to annul this reflection a positive divergent wave (54) must be supplied by the source to give a simple convergent field e^{ikd}/d.

It is of interest to see what result the *accelerating* Green's Function gives in the case of the divergent wave. Upon reversing the sign of k in (41) it turns out that integration over the inner sphere gives

$$\varphi = \frac{e^{ikd}}{d}, \tag{55}$$

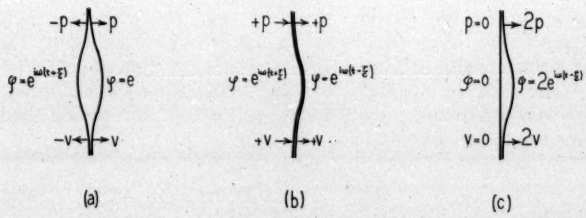
and the integral over the outer sphere gives

$$\varphi = \frac{e^{-ikd}}{d} - \frac{e^{ikd}}{d}, \tag{56}$$

the sum of which gives the correct result e^{-ikd}/d. This checks the statement previously made that the use of accelerated quantities is just as valid as the conventional retarded quantities.

The following simple physical picture may help to visualize and clarify the relations between the general theorem (41) and the classical theorems (44) and (45). Figure 3 (*a*) repre-

FIG. 3.



sents symbolically a *simple* surface source comprising two juxtaposed surfaces vibrating in opposition. The character of the waves emanating from the two sides and the p and v relations are indicated. The velocity potential due to the source is expressed by (44). Similarly 3 (*b*) represents a *double* source, comprising a single membrane; this can be regarded as formed by the two juxtaposed membranes vibrat-

ing with equal velocities as shown in the diagram. The φ due to this source is given by (45). Now let these sources be superposed. The result is shown at 3 (*c*). The waves to the left cancel out, the motion of the left-hand membrane in (*a*) is reduced to zero; the wave to the right is doubled and the motion of the right-hand membrane is doubled. The resultant φ is the sum of (44) and (45) which is equivalent to (41) (multiplied by 2). (*c*) is a *composite* source with discontinuities in both p and v and the general theorem (41) may be interpreted as giving the potential of such a composite source. We may therefore regard a distribution of composite sources as the acoustical analogue of the equivalent Green distribution in the theory of electrostatics. A wave field in free space may properly be represented by a distribution of composite sources, whereas neither of the fundamental types of sources (*a*) or (*b*) is capable of such representation. One characteristic of this type of source, as shown in Fig. 3 (*c*), is the absence of radiation from the rear. Physically we can therefore replace the wave field by a physical surface vibrating unilaterally and radiating on the side facing the observation point. In our problem of calculating the φ due to a point source, we can represent the point source by spreading a composite source over a spherical surface surrounding it; there is no radiation into the interior. If we had attempted to use theorem (44) in the calculation, as is customary, this would have been equivalent to spreading sources of the Fig. 3 (*a*) type over the surface and we should have obtained the equation (51) representing not only the divergent wave but also the radiation from the interior surface. The same remarks apply to the use of Fig. 3 (*b*) sources and theorem (45).

In the historical treatments of acoustics the theorem (44) is commonly applied to Fraunhofer diffraction problems, for example to the effect of an aperture in a screen upon which plane waves are incident. The assumption is made that the wave in the aperture is unaffected by presence of the screen. A typical example of such an application is found in Rayleigh (*loc. cit.*, p. 107). He states that, "if the value of $\partial\varphi/\partial n$ over the aperture be known formula—(equivalent to (44) above)—enables us to calculate φ on the further side." But this is equivalent to representing the wave field by a simple

source, Fig. 4 (*a*), which is improper. There is no discontinuity in $\partial\varphi/\partial n$ in crossing the aperture and the use of theorem (44) is unjustified. In order to calculate φ properly we may employ (41) but must know $\partial\varphi/\partial n$ and φ over a surface enclosing the observation point. $\partial\varphi/\partial n$ and φ may be assumed known over the aperture; $\partial\varphi/\partial n$ is zero over the screen, but we do not know φ over the screen. (The integration over the infinite sphere can be avoided if we consider a finite train of waves.) We have therefore insufficient data for the calculation of this problem.

The formula (44) is also extensively used to calculate the radiation from a piston in an infinite baffle. Here we are faced with much the same type of difficulty. We know $\partial\varphi/\partial n$ over the face of the vibrating surface and the baffle but do not know what φ is. The customary use of (44) of the textbooks is therefore improper in this case also.

RANDOM FRACTURE OF A BRITTLE SOLID.

BY

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INTRODUCTION.*

A brittle solid may be defined as one having a tenacity small in comparison with its rigidity. Such a material readily yields new surface by shattering under random impulsive or crushing forces producing deformation by action at the boundary. Many solids upon which the crushing or grinding mill acts fall into this category. The problem of the mill may be defined as one which concerns itself with the relations between the fragment statistics, the properties of the material, and a set of random mechanical boundary conditions.

The production of cracks and fissures in brittle solids under random and organized boundary conditions has been studied by Suzuki,[14] Terada [11] and Hirata.[12] Hirata has shown that a fundamental statistical attack on the problem is possible by his use of the Poisson series to describe fracture statistics. The grinding mill has been studied extensively by empirical methods and attempts have been made to relate the fragment statistics to the boundary work. The names of Martin [8, 9] and Gaudin [10] are identified with much painstaking work here. The need for a rational approach to the task of specifying and predicting the probable size and shape of the fragment is widely felt. The purpose of this paper is to map out such an approach.

Despite numerous complications of the general case, the applicability of three general principles is quite clear. In all discussions "chance" must be assumed to play a dominant role.

* The author takes this opportunity to acknowledge the valued suggestions of Stephen P. Burke and Maurice C. Holmes of West Virginia University; and William Bender and Nicholas Rashevsky of the University of Chicago. Opportunities for study accorded by a Fellowship of the Social Science Research Council contributed to an understanding of psychophysical problems involved in this research.

The ordinary conservation principles are not disputed except in regard to the mode of their application. The manner in which chance enters the phenomena may be stated in alternate ways. The first is a variant of the entropy principle and states that the surface of a brittle material is either increasing or stationary. From the point of view of fine structure this may be interpreted as corresponding to the randomness of the fracture surface throughout the solid. By assuming ordinary elastic solid theory valid up to the instant of fracture, this principle permits the calculation of the size and shape probabilities of the fragment. To deal satisfactorily with the problem of very small fragments the distinction between perfect and statistical homogeneity must be preserved. Surface friction and plastic deformations are supposed negligible. The one-dimensional form of the Poisson " Law of Small Numbers " gives the required distribution functions and is discussed independently of its mechanical setting. The mechanical relations are developed and the principle $dS \geq 0$ then establishes a possible interpretation of the statistical parameters. The equation of new surface and the Poisson Law yield the size-shape probabilities for the case of the three-dimensional statistically homogeneous isotropic brittle solid. The resulting formulæ agree with intuitive expectation and the systematic experiences of Martin, Gaudin and Hirata. Fracture statistics for 1200 thin rods are analyzed and a mechanical model of the Poisson series is described.

RANDOM SEGMENTATION OF A STRAIGHT LINE.

Consider a straight line of indefinite extension upon which points are distributed at random with a constant expected density of $1/\bar{s}$ per unit length. Choose a segment of the line so that one of its termini coincides with an arbitrary point of the random set. Let it extend from that point in either sense a distance s. The probability that this segment contains n points of the set is then given by the Poisson Law:[1]

$$P(n) = \frac{1}{n!}(s/\bar{s})^n e^{-s/\bar{s}}. \qquad (1)$$

The chance that no points fall within the interval s is thus:

$$P(0) = e^{-s/\bar{s}} \qquad (2)$$

But this is also the chance that an arbitrary segment of the line bounded by two successive points of the random set has a length s or greater. A finite interval L, large in comparison with $\bar{s}$, will therefore have a probable content of whole segments given by the largest integer smaller than

$$N = L/\bar{s}. \qquad N \gg 1 \quad (3)$$

Hence a large but finite number N of segments derived by sampling an infinite homogeneous population may be expected to contain ν oversize-s segments, where ν is very nearly

$$\nu(> s) = Ne^{-s/\bar{s}}, \qquad N \gg 1 \quad (4)$$

where L is the aggregate length of the sample and $\bar{s}$ is estimated from (3).

HETEROGENEOUS AGGREGATE OF LINEAR SEGMENTS.

Let m lines be segmented at random so that the ith line has a mean segment length $\bar{s}_i$. If an interval of length L_i is taken from each line, the ith and the kth intervals are indistinguishable except as to the mean density of points. The density of points in the ith line provided N_i is large, is given very nearly by

$$N_i = L_i/\bar{s}_i. \qquad N_i \gg 1 \quad (5)$$

Then

$$\frac{N_i}{N_1} = \frac{\bar{s}_1}{\bar{s}_i}\frac{L_i}{L_1}. \quad (6)$$

The total number of segments in all intervals is

$$N_0 = \sum^{m} N_i. \quad (7)$$

If a segment be chosen at random from the aggregate of all segments, the probability that it comes from the ith class is

$$p_i = \frac{N_i}{N_0}, \quad (8)$$

whence

$$\frac{1}{\bar{s}_i} = \frac{p_i L_1}{p_1 L_i \bar{s}_1}. \quad (9)$$

The distribution of oversize segments for the typical component is then

$$\nu_i = N_0 p_i e^{-s/\bar{s}_i} \tag{10}$$

or for the heterogeneous aggregate is

$$\nu_0(> s) = N_0 \sum_{i}^{m} p_i e^{-s/\bar{s}_i}. \tag{11}$$

Several cases are of interest. When $L_i = L_1$, a selective principle may be operative (e.g., we choose the components as in the experiments below, where 1200 six inch rods were selected for fracture). If m is large, the relative contribution of any source small, and no source tends to predominate, i.e., $1/m$ is the expected value of p_i, then

$$\nu_0(> s) = N_0 e^{-s/\bar{s}_m}, \tag{12}$$

where

$$\bar{s}_m = mL/N_0 \tag{13}$$

or, measuring the N_0 segments j individually and taking their mean length as an estimate $\bar{s}_m'$ of the hypothetical mean $\bar{s}_m$,

$$N_0 \bar{s}_m' = \sum_{j}^{N_0} s_j. \qquad N_0 \gg 1 \tag{14}$$

When $L_i \neq L_1$, the initial distribution of L_i must be known. Suppose L_i is itself a member of a homogeneous random set of segments. Let the m segments L_i be reassembled and the line be supplied with additional random points. The mean length for the new set of segments will be smaller but the form (12) will again hold.

In general, a finite number of terms of ν_0 can be equated to a function of s, non-increasing in $(0 < s)$. By differentiation and summation one obtains as many equations as there are undetermined coefficients in the series ν_0. A heterogeneous experimental sample has a corresponding set of summation coefficients or "moments" from which the coefficients of the hypothetical population can be determined. Such coefficients will always be qualified by sets of uncertainty limits associated with random sampling. These increase with the order of the terms in ν_0 and it is not in general significant to extend the series indefinitely. Four summation "moments" are needed to determine two terms. Beyond this

the sampling error increases rapidly for ordinary sample sizes (500–5000). The form (12) (and (78) below) is Pearson's Type III curve and may be fitted by his methods. The criterion of " Goodness of Fit " can be applied to estimate the significance of observed departures in a sample.

SAMPLING FLUCTUATIONS OF $\bar{s}_m$ FOR A HOMOGENEOUS POPULATION OF SEGMENTS.

Let a homogeneous isotropic one-dimensional space be segmented at random and let m samples, each having an aggregate extension L, be taken at random from the space. The expected number of segments is by (13)

$$N_0 = mL/\bar{s}_m \tag{15}$$

and the standard deviation of N_0 is that of the Poisson Law. It is $\sqrt{N_0}$. If the value of $\bar{s}_m$ is to be estimated by measuring and counting the segments, the successive samples will show an unknown fluctuation of $\bar{s}_m'$ the estimate, from $\bar{s}_m$ the hypothetical mean. When N_0 is moderately large (> 10) it can be shown that the Poisson Law reduces by close approximation to the normal error function, whose mean and most probable value then become N_0, and standard deviation $\sqrt{N_0}$. It follows that particular samples of N_0, as N_{0r}', will tend to fall within the limits,

$$N_0 \pm \sqrt{N_0}, \tag{16}$$

in approximately 68 out of 100 trials. If mL be the aggregate length of the samples, the corresponding limits on $\bar{s}_m'$ are

$$\bar{s}_m \pm \delta\bar{s}_m = mL/(N_0 \mp \sqrt{N_0}) \tag{17}$$

or

$$\delta\bar{s}_m = \bar{s}_m/\sqrt{N_0}, \tag{18}$$

where the higher terms of the expansion have been neglected.

In estimating the sampling " error " of the mean fragment length in a particular set of samples we must rely upon the particular estimates $\bar{s}_{mr}'$ and N_{0r}', $r = 1, 2 \cdots$, for the hypothetical population is unknown.

If now, α sets of m samples each are taken from the same population, $\bar{s}_{mr}'$ will fluctuate about a central tendency; call

this $\bar{s}_{m\alpha}'$. If the samples come from the same population, then the α instances of $\bar{s}_m'$ may with fair approximation be supposed distributed in normal fashion, with a consequent 68 per cent. of the set in the range $\bar{s}_{m\alpha}' \pm \sigma$, where

$$\bar{s}_{m\alpha}' \equiv \frac{\sum^{\alpha} \bar{s}_{mr}'}{\alpha} \tag{19}$$

and

$$\sigma^2 \equiv \frac{\sum^{\alpha} (\bar{s}_{mr}' - \bar{s}_{m\alpha}')^2}{\alpha - 1}. \tag{20}$$

But $\delta\bar{s}_{mr}' = \bar{s}_{mr}'/\sqrt{N_{0r}'}$ and σ are experimental estimates of the same quantity, namely, the standard fluctuation of means. Hence if the set of α successive samples containing an aggregate extension αmL of segments comes from a homogeneous population, we may expect to find approximately that

$$\delta\bar{s}_{mr}' = \sigma. \tag{21}$$

That is, the sampling range of the mean for a particular sample tends to equal the dispersion of the sample means about the aggregate mean if the source of the samples is a homogeneous population.

The converse is not a necessary inference for the agreement (21) can result by chance, as can a disagreement. As α and N_{0r}' increase the chance of such a coincidence decreases, but never wholly vanishes. The test (21) may therefore be viewed only as a partial indicator of the probable homogeneity of the set of samples. By the use of the tabular error function or, what is simpler, Tchebychev's formula for the chance of an observed deviation, we can estimate more or less precisely the chance that an observed disagreement would result from sampling alone.

As a rough general rule, differences greater than two or three standard units, $\delta\bar{s}_m$, can be taken as a signal that the sources may be heterogeneous. Differences less than this cannot be accepted without the qualification that they could have resulted from chance. The search for heterogeneities is, however, somewhat less imperative.

STATISTICAL HOMOGENEITY.

The foregoing results are readily applicable to the fragmentation of brittle solids under random boundary conditions if certain restrictions on the qualities of the material are noted, and a distinction drawn between perfect and statistical homogeneity in these qualities. The space in which the segmented line is immersed is here assumed such that the properties of its elements are invariant to translation and rotation. The point events on the line have an all-or-none character in that they either occur or are not in evidence. We consider how these ideal properties are simulated in reality.

Real solids exhibit a tendency to deform more or less under the action of boundary forces. For convenience we restrict this preliminary study to highly rigid solids. All solids exhibit some tendency, however slight, toward plastic or permanent deformation. In contradistinction, the elastic solid resumes its initial configuration when deforming forces are removed and, in the ideal case, returns to the source potential energy of strain. It is convenient to restrict the discussion to highly elastic solids which obey Hooke's Law to the fracture point. Rupturing forces may be conceived to produce failure in one or both of two possible ways. One is by slipping along planes of positive tension. We assume that an elastic solid fails in the second way only, namely, by parting along positive tension surfaces at a uniform ultimate stress. This is sufficient to show that such a solid fails completely if fracture initiates at all.

Among various qualities here relevant to the discussion are the density, bulk and shear moduli of elasticity, etc. Whether or not we predicate homogeneity with respect to such qualities in any real material is partly a matter of aims and discrimination. For certain purposes and sensibilities of observation a material like sandstone is homogeneous and isotropic. For other purposes and finer orders of discrimination, the same material has a heterogeneous fine structure and natural bedding planes. Yet the material remains what it was from the first standpoint if we choose to return to it.

For definiteness we take a simple but fundamental example. Except as to extension we leave aside the question of isotropy by considering a thin brittle rod such as a pencil

lead, attending first to its gross geometry. Let it be supposed that the purposes in hand are well suited if we use a measuring rod divided into L/Δ categories or least counts, where L is the absolute length of the rod and Δ that of the least count. The precision of measure in this standpoint may be defined by

$$h = \frac{L}{\Delta} > 1. \tag{22}$$

In comparison with L, we have thus chosen to regard quantities of order Δ or smaller as physically negligible in length. Accordingly, a solid of dimensions $\Delta \times \Delta \times \Delta$ is the physical representative of the mathematical point, and may be termed the physical point. If the rod chosen for fracture be of length L and diameter Δ, let it be termed "thin." If the departure of the axis from its tangent in an arc distance L is of order L, the rod is "sensibly straight."

The sensible uniformity of the cross-section and shape can to the same order be tested by axial translation of a screw gauge consistent with and having the same precision of measurement as the meter rod. The section of the rod is uniform to the order h if the relative fluctuations in shape and diameter are of the order Δ/L. In general, finer examination reveals random irregularities of the surface and voids within the boundaries having an absolute fractional level $f_1\Delta$ with respect to Δ. Still finer observation might reveal a granular structure. In general, an indefinite fineness of structure f can be postulated. The series of observations relating the conventional sensibility of observation to the actual and possible inhomogeneity of structure is thus *

$$h = \frac{L}{\Delta} \geq \sqrt{\frac{4}{\pi}} > 1 \geq f_i \geq f > 0. \tag{23}$$

Equality of f to zero is excluded since this would imply that the observer had somehow transcended the finite discriminatory power of his senses. The case $f = 0$ would correspond to ultimate continuity of structure and the idealized observer who transcends current or permanent restrictions on his powers of observation. The real observer implements his

* The conditions on h are deduced later (equations 55 and 81).

senses in any way that suits his purposes short of current psychophysical limitations which become effective at a diffuse absolute level. The fine structure f may or may not lie beyond this vaguely defined region. In the former case postulation is permissible but can be forced to remain properly mindful of its task by explicit inclusion of f in calculations.

In the present experiments $L = 6.1''$, $\Delta = .078''$, $f_1\Delta = .003''$, $f_2\Delta = .00002''$, $f > 0$. A steel scale, screw micrometer, and microscope were used in specifying the macroscopic and microscopic configuration of the material. In this case, f_1 was a characteristic void in the structure and f_2 the level of the largest particulate structure of the material. The physical point was taken as any solid of dimensions 0.078^3 in.^{3} or smaller. In compiling the fragment statistics particles of this order were discarded.

The structural homogeneity of the material may be measured by the number of qualitatively similar grains contained in a physical point

$$\geqq 1/f^3,$$

where f is left indefinite in order to keep open the question of what structural level is involved in the determination of macroscopic qualities.

Qualities which are here relevant to fracture are the shear modulus μ, bulk modulus k, density D, ultimate tensile stress u, and a displacement of rupture l. Obviously these depend upon the qualities of the structure, gross and molecular. It is well-known that u depends largely upon the density of first order voids in the structure.[2, 3] Stability in the value of any parameter depends upon the existence of very large numbers of qualitative fluctuations within the physical point. Hence to attain statistical stability in u, etc., f should be small.

Statistical homogeneity and isotropy can be defined in terms of the conventionally permissible relative fluctuation $1/h$ and the concept of random sampling. If the relative fluctuation in successive samples of any quality tends to be $1/h$ and this is independent of " physical position " or orientation to the same order, the material is statistically homogeneous to that order. A high degree of homogeneity assures that the nature of the material itself will not predispose

fracture " at " some physical points rather than others. The chance stress concentrations which lead to initial failure then tend to be very numerous within the physical point. Initial stresses, if large or organized, predispose fracture as to position, orientation and time. Hence, preëxisting stresses must be negligible judged by the same criterion.

The vagueness with which this criterion, ordinarily thought of as the " error of measurement," is used in physics leads to considerable disagreement as to what constitutes a good fit of theory to experiment. Here, however, we carefully distinguish between ordinary errors of observation as measured by Δ/L, and sampling fluctuations, $\delta\bar{s}_m$. Even when the material is homogeneous to a high order in all relevant qualities as measured by h, the judgment of fitness of the theory is qualified by a statement of the sampling fluctuations, equation (18).

(*To be continued.*)

A STUDY OF THE QUALITY, THE DESIGN AND THE ECONOMY OF CONCRETE.

BY

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INTRODUCTION.

The knowledge of concrete making has made a remarkably rapid advance during the last fifteen years. This advance was principally brought about by the stimulus given to scientific investigations by the publication of the water-cement ratio law by Professor D. A. Abrams (1).* Investigations into the properties of concrete and its ingredients were undertaken or given new impetus at a number of the best equipped universities in the country, and also pushed ahead by the cement producers themselves. The publications of these various investigations brought forth a great variety of results, the interpretation of which led to many different theories. Thus we received the cement-void ratio, the cement-space ratio, the water-cement ratio laws, and many others. It would lead too far to even mention all the different viewpoints which were sponsored by different individuals and groups. One thing seemed to be lacking. That was the correlation between the different theories, the harmony between the different results. The main purpose of the study presented in this paper is to correlate some of the most important developments and to attempt to bring the whole problem of concrete and its various qualities in under one single conception, one basic law. This law is being advanced as the cement concentration law for strength and other qualities of concrete.

Furthermore, the problem of design and control of concrete mixes is a very vital one. Each theoretical conception usually brought forth its own method of design. Thus we received the fineness modulus, the surface modulus, the surface

* These numbers refer to list of references at the end of the paper.

area, and many other methods. Consequently there was no generally accepted basis for the designing of concrete mixes. In this paper a method of design recently developed at Lehigh University will be presented because of its simplicity and other advantages. It will lead too far to include any more data than those essential for a sound proof of the advanced theories. Most of the data has been secured directly by the author, supplementary data have been obtained from published reports.

In the carrying out of the above studies, a problem which heretofore has been very elusive and entirely beyond basic relationships was solved on a definitely rational basis. This problem was the one on the relationship between quality and economy of concrete. Although this relationship came in as an unforeseen consequence of the other problems, it probably is the most outstanding of all in its practical aspects because it deals with the most fundamental of all practical problems, namely that of designing on basis of economy.

The paper is therefore divided into three major parts, one on Qualities, one on Design, and one on Economy of concrete.

ACKNOWLEDGMENT.

Without the excellent research facilities of the Portland Cement Association and the Fritz Engineering Laboratory at Lehigh University, most of the investigational work leading to the theories and conclusions given in this paper would have been difficult, if not impossible. The many valuable advices and constant encouragement given by Mr. F. R. McMillan, Director of Research, Portland Cement Association, and by the late Professor W. A. Slater, Director of the Fritz Engineering Laboratory, Lehigh University, proved very helpful and contributed much towards the final solution of the problems presented.

PART I. THE QUALITIES OF CONCRETE.

a. The Concrete.

Concrete is a mixture of a binding part, the cement paste, and a filler, the aggregate. The cement paste consists of cement and water which during the hardening process, combine chemically and bind the inert aggregate into a solid mass.

In properly produced concrete the cement paste coats all aggregate particles and fills all spaces between the particles so that the unit volume of concrete consists only of the volume of the paste plus the volume of the aggregate. Since the cement paste is made up of the cement and the water, the volume of the paste is equal to the volume of the cement plus the volume of the water. By volume is here meant the volume of displacement which more commonly is termed the absolute volume. Fig. 1 illustrates how a unit volume of concrete is made up of the different ingredients.

FIG. 1.

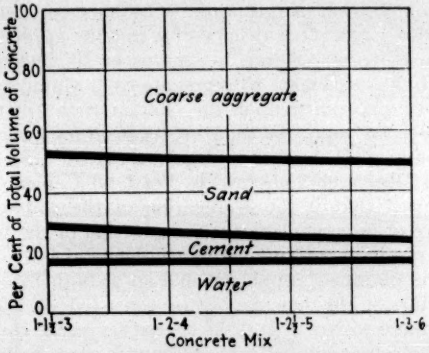


Illustration of relative amounts of ingredients in a unit volume of concrete.

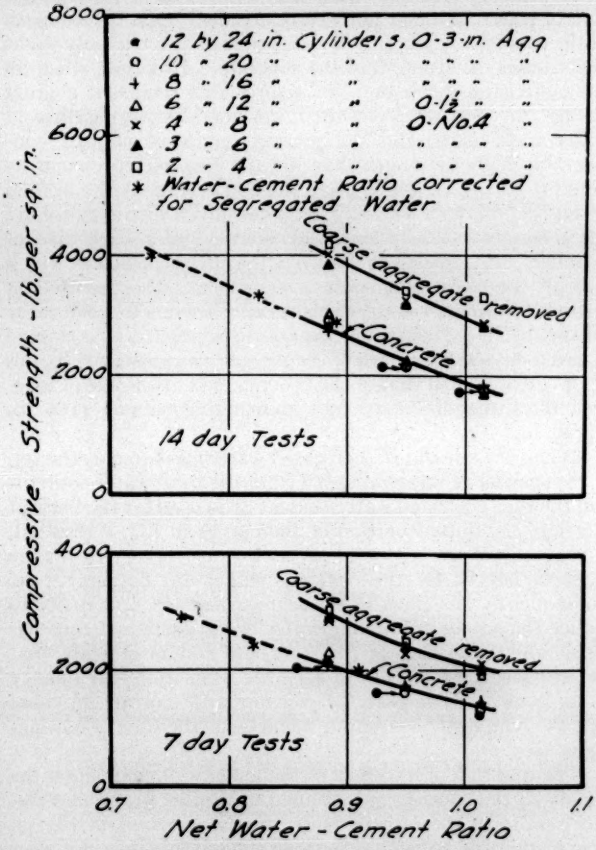
Concrete may therefore be divided into the two portions, the cement paste which primarily determines the qualities of the concrete, and the aggregate which serves as the filler. At first a study was made of the paste for the purpose of establishing its function and then the aggregates were studied for their effect upon the concrete.

b. The Cement Paste.

The concrete consists of two parts, the cement paste which is the active part, and the aggregate which is the inert filler. In order to study some of the limitation of the water-cement ratio law, investigations were carried out on the effect of the

water content in, as well as of the amount of the paste upon the qualities of the concrete. The phenomena of segregation of water from the paste is noted in all overwet mixes, and the question of how this segregation affects the quality of the resulting concrete became more important as the art of accurate control of concrete mixes improved. When segregation takes place, the water accumulates at the top of the concrete and the water content in the paste itself is changed correspondingly. Since it is the water retained by the paste at the time of hardening which determines the quality of the paste, the segregated water should be measured and subtracted from the mixing water in order to give a correct value for the composition of the paste. Ordinary concrete having well graded aggregates does not segregate appreciably for consistencies corresponding to slumps of six inches or less. Mortar, however, starts to segregate at a slump of two to four inches, depending upon the characteristics of the sand. The coarser the sand, the more segregation for a mortar of a given slump. The results of this investigation (Series J–110 Group II, Research Laboratory, Portland Cement Association) showed that if the segregation of the water was not taken care of in computing the composition of the paste, the strength results would not follow the general law. Some of the results obtained are shown in Fig. 2, both for concretes and mortars. The fine aggregate consisted of Elgin sand graded from 0 to No. 4, and the coarse aggregate consisted of Chicago limestone graded uniformly up to three inches. The size of the test cylinders used, varied from 12 by 24-inch to 2 by 4-inch in order to secure a comparison between the strength of the concrete when tested in a cylinder of suitable size without removing any of the large particles of aggregate and that of the same concrete when molded in smaller specimens after removal of all or part of the coarse aggregate particles. Cylinders 8 by 16 inches or larger contained all the coarse aggregate while all material coarser than the 1½ inch size was removed in molding the 6 by 12-inch cylinders. For the 4 by 8-inch, 3 by 6-inch, and 2 by 4-inch cylinders all coarse aggregate was removed. All molds were sealed by means of paraffin so that no leakage occurred and the amount of water accumulated on the top of the specimens represented the segregated water and was measured.

FIG. 2.



Effect of segregation of mixing water on strength of concrete.

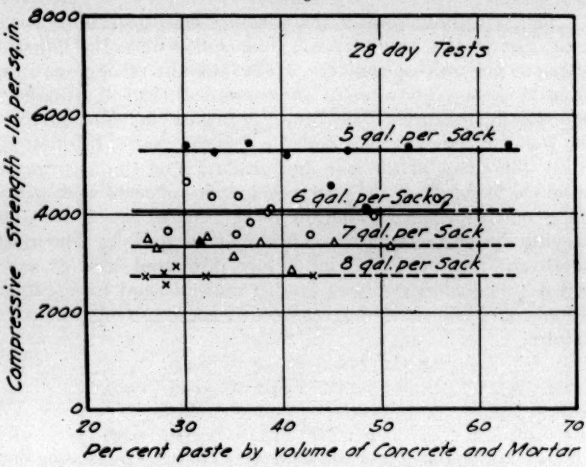
All the concrete mixes showed practically no segregation, although the slump was seven inches and more. The removal of the aggregate between the 1½-inch and 3-inch sizes did

not materially alter the consistency of the mix or the segregation of water, and had practically no effect upon the strength of the concrete. The size of test specimen also had only slight effect upon the strength of the concrete. However, when all the aggregate above the No. 4 sieve was removed, a great change in consistency resulted, considerable segregation of water took place, and the mortar specimens showed considerably higher strength than did the concrete specimens as noted from Fig. 2, which gives the test results at the ages of seven and fourteen days. The values given in the figure are the averages of the four specimens used for each size of cylinder. It is seen that the strengths of the specimens which had all the coarse aggregate screened out, when plotted in terms of the original water-cement ratio, are much above those for the specimens containing the coarse aggregate. At the age of seven days the strength of the mortar was about 700 lb. per sq. in. greater than that of the concrete and at the age of fourteen days the difference had increased to about 1100 lb. per sq. in.

When the amount of segregated water measured at the top of the specimens was subtracted from the total water content, and the thus corrected water-cement ratio used for the basis of plotting, the dotted portion of the curves in Fig. 2 resulted. It is noted that these dotted curves line up very well with the strength curves for the concrete which did not segregate. Consequently the effect of the segregation was principally to reduce the amount of mixing water in the paste and thus decrease the water-cement ratio. These results indicate that the water-cement ratio is an accurate measure of the quality of the cement paste both for concrete and mortar, provided that the true water content in the mass at the time of hardening is used.

The question of the effect of the amount of paste upon the quality of the concrete was studied in another group of tests. The results of these tests which are summarized in Fig. 3, showed that the amount of paste in the mixture does not alter the strength as long as the composition of the paste remains constant. The variation in amount of paste was brought about by using various proportions of fine to coarse aggregate for a paste of a given water-cement ratio. Each point in

FIG. 3.



Effect of amount of paste on strength of concrete and mortars.

Fig. 3 represents the average strength of five specimens made from workable mortar or concrete. No correction has been made for the amount of water absorbed by the aggregate, and some of the irregularities in the results would be reduced by such a correction. The specimens containing only 30 per cent. paste show just about the same strength as do specimens containing as much as 63 per cent. paste so long as the water-cement ratio of the paste is maintained constant.

These investigations to a large extent proved that the strength of the concrete is fixed primarily by the actual water-cement ratio of the cement paste at the time of hardening. In order to obtain a true water-cement ratio strength relation it is therefore necessary to deal with concrete having little or no segregation, or measure the amount of segregated water and make allowance for this in the interpretation of the results. Although the strength of the concrete is little, if any affected by the amount of the paste, the workability of the concrete is largely controlled by the paste content.

c. The Aggregate.

The prime function of the concrete aggregate is to serve as a filler in the cement paste and thus reduce the amount of paste per unit of concrete. The amount of aggregate to be used is therefore more of an economical than of a quality-determining nature. The more aggregate in the concrete, the less the cement paste and the less the cost. In order to study the effect of the size and gradation of the aggregates upon the strength of the concrete, a series of tests were made using one type and gradation of the coarse aggregate and varying the size and gradation of the fine material. The most important results of this study are presented in Figs. 4, 5, and 6. The sand was well graded natural sand from Elgin, Illinois, and the coarse aggregate was Elgin gravel graded as follows:

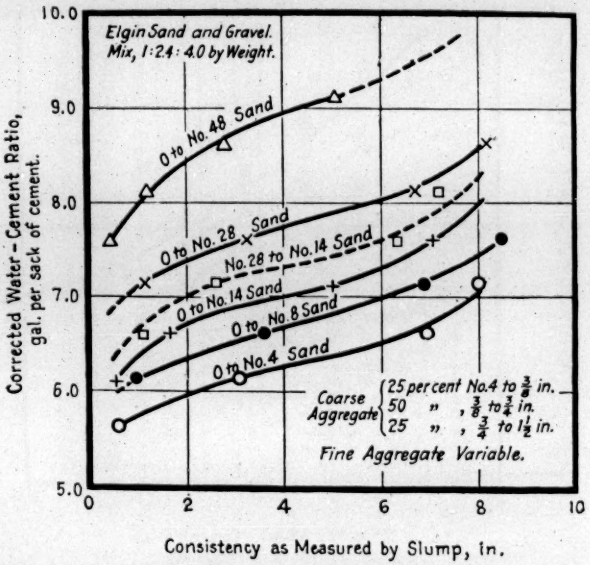
25 per cent.—No. 4 to ⅜-in.
25 per cent.—⅜-in. to ¾-in.
and 50 per cent.—¾-in. to 1½-in.

The size and gradation of the sand were changed by sieving out certain parts of the sand. Thus a series of different fine materials resulted, sizes of which were as follows: 0 to No. 4, No. 48 to No. 4, 0 to No. 8, 0 to No. 14, 0 to No. 28, 0 to No. 48, No. 48 to No. 28, No. 28 to No. 14 and No. 14 to No. 8, Tyler sieves being used.

The concrete mix remained constant at 1 : 2.4 : 4.0 by weight. Thus the only variables were the characteristics of the fine aggregate and the amount of water required for a placeable consistency. In Fig. 4 the net water requirement has been plotted for the different consistencies of the concrete. For any given slump the amount of water increased with the increase in fineness of the sand. While the 0 to No. 4 sand required only six gallons per sack of cement, the 0 to No. 48 sand required 8½ gallons for a 2-inch slump. However, the general trend of the relationship between the water requirement and the consistency of the concrete is the same, regardless of the sand used.

In Fig. 5 the compressive strengths of the concrete specimens have been plotted against the net water-cement ratio of the mix. It is noted that for all ordinary sand sizes,

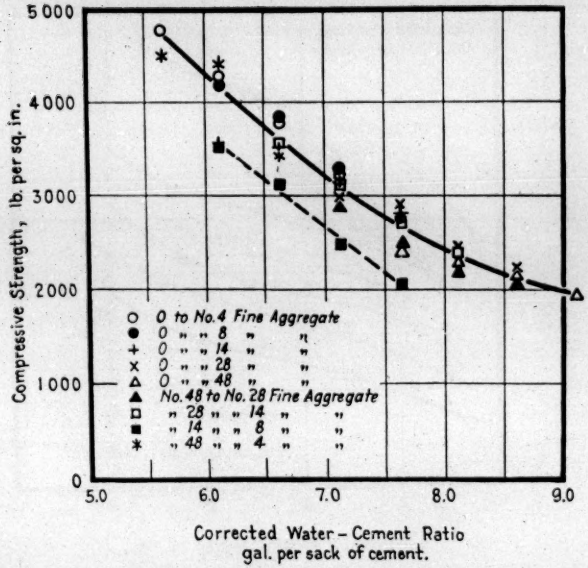
FIG. 4.



Effect of size and grading of fine aggregate on consistency of concrete.

the strengths follow fairly well one common water-cement-ratio-strength curve. Only the very harsh mix which resulted from the use of only one relative coarse grain size in the sand, that is, only the material between the two consecutive sieves, No. 14 and No. 8, showed a marked divergence from the common curve. The strength of this harsh concrete was about 500 lb. per sq. in. less than that of the other mixes having the same water-cement ratio. This indicates very strongly that the strength of the concrete is very little affected by the size and gradation of the fine material as long as the concrete remains placeable. It is the quality of the cementing paste which determines the strength. Since the quality of the paste must be the same in order to give the same strength of the concrete, it is seen that the quantity of a paste of a

FIG. 5.

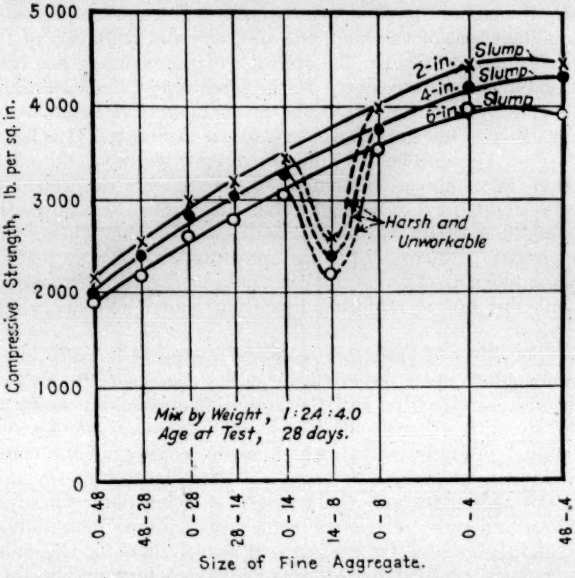

5 000
4 000
3 000
2 000
1 000
0
Compressive Strength, lb. per sq. in.
5.0
6.0
7.0
8.0
9.0
Corrected Water – Cement Ratio
gal. per sack of cement.
○ 0 to No. 4 Fine Aggregate
● 0 " " 8 " "
+ 0 " " 14 " "
× 0 " " 28 " "
△ 0 " " 48 " "
▲ No. 48 to No. 28 Fine Aggregate
□ " 28 " " 14 " "
■ " 14 " " 8 " "
✱ " 48 " " 4 " "

Relation between water-cement ratio and strength of concrete with different sizes and gradings of fine aggregate.

given composition varies greatly with the size and gradation of the fine aggregates. For a given quality the amount of paste must be considerably greater for producing a given placeability of a mix containing very fine sand, than for a mix containing relatively coarse sand. The question of the aggregate is therefore primarily one of economy. That fine material which produces concrete of the given quality at the least cost, is naturally the one to choose.

In order to visualize the strength of the concrete used in this investigation in terms of the size of fine material and amount of slump, Fig. 6 was prepared. The strength of the concrete, which had a given proportion, increased rapidly with the increase in coarseness of the sand until the original 0 to

FIG. 6.



Effect of size and grading of fine aggregate on strength of concrete of given mix and slump.

No. 4 sand was reached. When the very fine material (0 to No. 48) had been removed from the original sand, the strength was still about the same as before this removal, but the placeability was somewhat decreased due to increased harshness, although the slump was nearly the same for the same water content. The very harsh mix containing only the No. 14 to No. 8 size sand does not line up with the other mixes. Due to its harshness and lack of placeability it falls far short of its position by size. Fig. 6 also brings out the advantage of a stiff mix (low slump) as compared with a more plastic mix.

The important conclusion drawn from this investigation was that the strength of the concrete was determined by the composition of its cementing paste, the gradation of the fine

aggregate having little or no influence beyond that of controlling the amount of paste necessary for a given placeability.

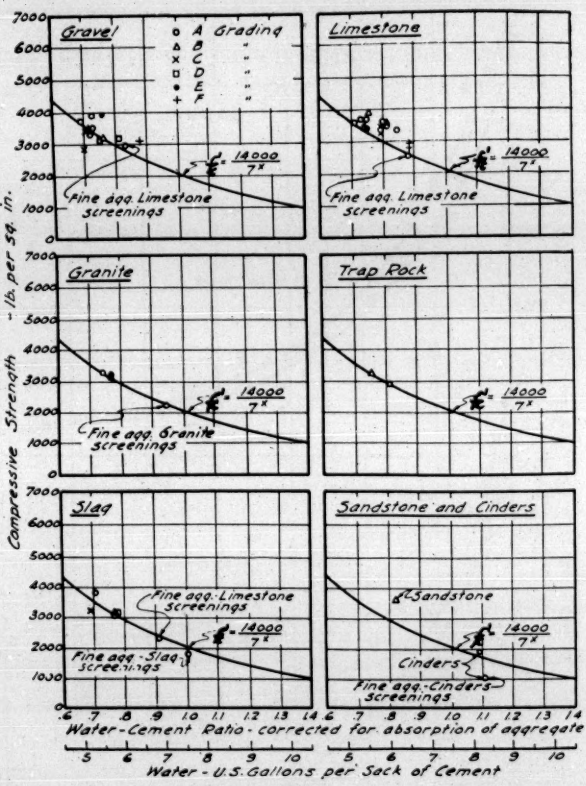
The effect of the kind, the size, and the gradation of the coarse aggregate upon the strength of the concrete has been studied rather extensively at the laboratory of the Portland Cement Association (2). The most illustrative summary of the effect of kind of aggregate is given in Fig. 7. It is noted that for the number of different aggregates used, the effect upon the compressive strength of the concrete was generally very slight; in fact so slight that for practical purposes the strength may be considered unaffected by the type of the aggregate. Naturally the amount of paste needed for a given placeability is different for the different aggregates, smooth sand and gravel requiring less than cinder screenings and cinders.

The effect of gradation of coarse aggregate has also but a minor effect upon the strength of the concrete. As long as the mix is placeable and the gradation reasonably uniform, the strength is hardly affected at all. However, too great a "jump" in gradation (3), which means leaving out too many of the individual sizes in a row, will cause lack of interlocking of the aggregates and the strength is somewhat reduced as shown in Fig. 8. The effect of the large "jump" in gradation is slightly greater for the smooth gravel than for the more irregularly crushed limestones, which is quite in harmony with the statement that the lack of interlocking affects the results.

The maximum size of uniformly graded coarse aggregate was found to have little if any effect upon the compressive strength of the concrete. Fig. 2 showed that the strength of mortars as well as of concrete with aggregate as large as three inches, grouped themselves along the same water-cement ratio curve as long as the test specimen was sufficiently large for the maximum size of particles.

It is therefore concluded that the compressive strength of the concrete is primarily determined by the composition of its paste with only slight variations directly attributable to the aggregate. However, the quantity of paste is to a large extent, controlled by the characteristics of the aggregate for any given placeability of the concrete. Consequently the

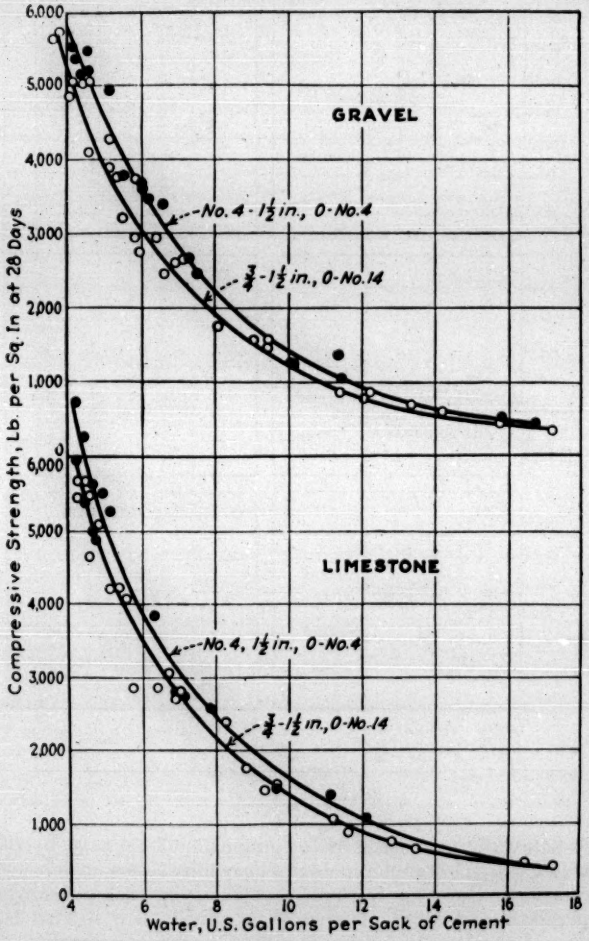
FIG. 7.



Effect of kind of coarse aggregate on strength of concrete. From Gonnerman and Shuman.

economy of the concrete is to some extent influenced by the aggregate. How much could not be readily ascertained before a rational basis for the study of the relationship between quality and economy of concrete was available. In Part III this relationship is developed and the economic function of the aggregates studied more in detail.

FIG. 8.



Effect of grading of coarse aggregate on strength of concrete. From McMillan.

(To be continued.)

A FURTHER STUDY OF OSCILLATORY CIRCUITS HAVING PERIODICALLY VARYING PARAMETERS.

BY

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(*Concluded.*)

PART II.

Experimental Results.

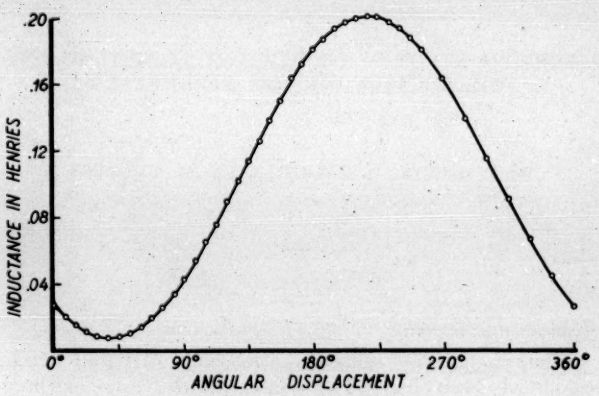
The spontaneous oscillation of resonant electrical circuits has already been observed by Winter-Günther [10] and has been produced here in the same manner by using a varying inductance, instead of a capacitance, in the dual circuit of Fig. 1*b*. The inductance variation * was of the form $L_0(1 + h \cos \alpha t)$, Fig. 6, instead of the postulated form $L_0/(1 + h \cos \alpha t)$, and was non-linear with the current due to the presence of iron. These two factors account for the incomplete agreement between predictions based on the idealized circuit and actual measurements.

An oscillogram showing a typical unstable spontaneous oscillation is reproduced in Fig. 7*a*, where the upper line represents the voltage across the circuit; the second, the marking from a commutator indicating the revolutions of the inductance; and the third, a 60 c.p.s. timing wave. The unstable oscillations began at the left of the oscillogram, where the short-circuiting switch S was opened, and increased in amplitude exponentially until the point x was reached, at which time the fuse, inserted to protect the apparatus, blew

[10] H. Winter-Günther, Jahr. der dr. Tel. und Tel., Vol. 34, p. 41 (1929) and Vol. 37, p. 172 (1931).

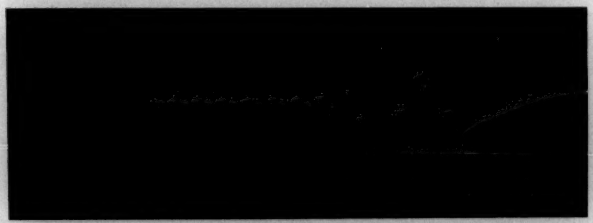
* A three-phase G. E. Selsyn Transformer, Model 2.179B1, was used. Two phases of the rotor and two phases of the stator were all connected in series.

FIG. 6.



The curve of the inductance $L(l)$ of the rotating inductor used in the experiments. A harmonic analysis showed the amplitude of the largest harmonics to be less than one per cent. of the fundamental amplitude.

FIG. 7*a*.



Oscillogram of an unstable spontaneous oscillation in the circuit of Fig. 1*b* for the conditions $\alpha = 2\omega_0 = 60 \cdot 2\pi$, $R = 500$ ohms. The upper curve is the current through the varying inductance; a fuse blew out at x. The middle line indicates each revolution of the inductor by its vertical displacement, and it shows the sudden deceleration of the inductor when the oscillation built up. The lower line is a 60 c.p.s. timing mark.

out. If a fuse was not used, the sudden load thrown on the motor was sufficient to endanger it electrically and mechanically and always reduced the speed to a value for which oscillations of an undamped periodic form took place. The de-

celeration was very rapid, the total process lasting but two or three cycles. This phenomenon is clearly illustrated by the oscillogram of Fig. 7*b*; also of note in the oscillogram is the change in wave form accompanying the change from an unstable type of oscillation during the exponential build-up to a final stable type of constant amplitude. Viewed in the light of the earlier discussions, this oscillogram shows the physically necessary shift from a region of instability, $\delta > 0$, to a region of stable spontaneous oscillation, $\delta = 0$. This shift was here effected by a change in α. It resulted in a change in the periodic function $\phi_1(\alpha t)$ and thus in the wave

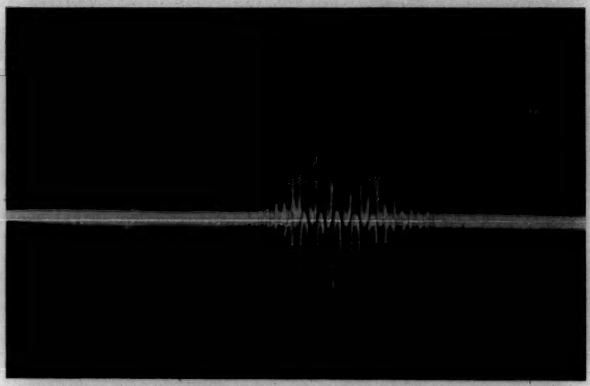
FIG. 7*b*.

Oscillogram similar to that of Fig. 7*a* except for the fact that the inductor speed was automatically reduced to a value giving stable spontaneous oscillations. Note the change in wave shape between the build-up period and the final stable condition; also observe the 2 : 1 reduction in speed.

form of the current—undoubtedly, non-linearity is in part responsible for the peculiar wave shape. The fundamental frequency of the current is $\omega_0 = \frac{1}{2}\alpha$ throughout the oscillogram.

Another way of producing this shift to stable oscillation is to use a resistance, whose magnitude increases with the current,[7] such as a metal filament lamp. Three 40-watt lamps were easily energized in this way. When the driving motor was accelerated so that the speed relationship $\alpha = 2\omega_0$ was rapidly swept through, a short transient current was generated. It had the general characteristics of the oscillogram of Fig. 7*c*, where the speed was rapidly changed from 1000 to 3500 r.p.m. The oscillation occurred at about 3000 r.p.m.

FIG. 7c.



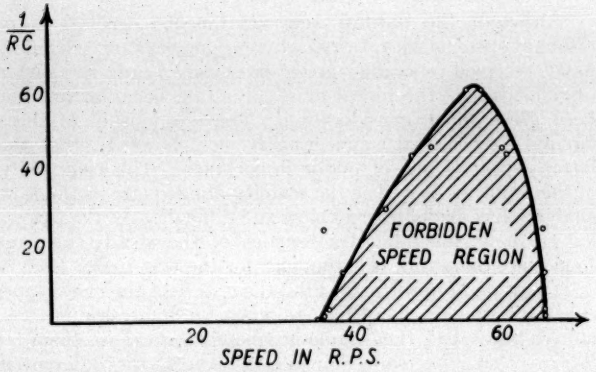
Oscillogram of current transient as inductor speed is rapidly swept through the critical ratio $\alpha = 2\omega_0$.

From the preceding discussion, it is clear that there are certain rates of variation that the inductance cannot assume if non-linear elements are not included in the circuit. The extent of these "forbidden speed regions" depends upon the power of the driving motor, saturation of the iron in the varying inductance, etc., but it may be determined for any given set-up. Figure 8 shows the region found for one of the particular laboratory arrangements used in these experiments; due to the difficulty of changing h, the quantity $1/RC$ was taken as the ordinate of this diagram. This figure may be considered as another way of representing the regions of unstable oscillation. Analogues of this forbidden speed region are found in the forbidden energy levels, orbits, etc. of modern atomic conceptions, in the forbidden zones of the spherical pendulum, and in other technical and theoretical problems.

An idea of the amount of power involved in these experiments is interesting. Several hundred watts could be delivered continuously to a lamp load. The power delivered to the varying-inductance was calculated approximately from measurements on the motor and was found to be up to 1.2 kilowatts for the transient oscillations of unstable nature, not

including the energy supplied by the deceleration of the motor and the Selsyn armatures, which would increase this estimate to several kilowatts. Inasmuch as the Selsyn unit had a rating of only 200 watts, it was unwise to go to still higher values of power, several shaft couplings having already been destroyed.

FIG. 8.



An experimentally obtained diagram of the forbidden speeds of one of the laboratory set-ups. It was impossible, with this particular apparatus, to drive the inductor at a speed corresponding to the shaded area.

The series circuit with varying inductance (Fig. 1*c*) was also studied, and it showed the same general characteristics as the parallel connection 1*b* or as the series connection 1*a* with varying capacitance. It appeared to be more critical and irregular, however, and results obtained at one time could not always be reproduced at another. For example, when oscillations were once initiated, they would continue after the adjustment was changed to a stable one. Passing a small direct current through the inductance helped to make the performance more regular, which indicates that the irregularity was largely due to the magnetic material in the variable inductance. When a lamp load was used, a peculiar periodic condition of oscillation and quiescence was sometimes observed. This was attributed to the thermal

inertia of the non-linear resistance. The lamps could be made to flash intermittently when this condition prevailed, and the period of the flash could be adjusted to any value between three seconds and thirty seconds.

Forced Oscillations with a Sinusoidal Motive Force.

Preliminary Discussion.

Although the natural and spontaneous oscillations of resonant systems with periodically varying elastance elements have received sporadic attention since Lord Rayleigh's original paper,[6] the forced or steady state behavior has not been given much consideration. The relationship of these circuits to electrical engineering is such, however, that the latter aspect is one of major importance. The complexity of the problem, as well as the scarcity of adequate methods of analysis, has made progress slow and difficult. In the following sections, several characteristics of the steady-state response are discussed, it is thought, for the first time.

The general problem is: Find the nature of the charge and current in the circuit of Fig. 1*a* when the impressed electromotive force has the simple harmonic form $V = V \sin (\nu t + \theta_0)$. Using the same notation as before, the differential equation is:

$$\frac{d^2Q}{dt^2} + \frac{R}{L}\frac{dQ}{dt} + [\omega_0^2 + \omega_0^2 h \cos \alpha t]Q = \frac{V}{L}\sin (\nu t + \theta_0). \quad (7)$$

In one respect, the present problem is less involved than that discussed in the preceding sections; because, a determination of the forced oscillations (or the steady state portion of the solution) is usually an easier task than that of finding the natural oscillations and the spontaneous ones (or the transient portion of the solution). On the other hand, two new parameters have been introduced, namely: the frequency $\nu/2\pi$ of the applied e.m.f., and its phase angle θ_0. Inasmuch as the circuit parameters are all independent of the charge and current, *the system is linear;* thus, the current dQ/dt is directly proportional to the applied e.m.f. V. Nevertheless, the steady state current may have components with fre-

quencies different from that of the applied e.m.f. Further, the current need not be composed of a fundamental frequency term and its harmonics, (i.e. a Fourier series), but, because the varying capacitance is an independent source of energy, capable of producing a current whose frequency may bear any relation to that of the applied e.m.f., components whose frequency is not an integral multiple of the fundamental may also be produced.

From the previous discussion of the natural and spontaneous behavior of the circuit, it is clear that both stable and unstable conditions may also occur when an applied alternating e.m.f. is impressed. Whenever the appropriate circuit adjustment is made, spontaneous oscillation will occur independently of any forced oscillations that may be present, but this condition is of minor interest when examining the forced behavior of the system. Therefore, we limit ourselves to those adjustments for which spontaneous oscillation is impossible.

The ratios of the three frequencies $\omega_0/2\pi$, $\alpha/2\pi$, $\nu/2\pi$ are important in determining the nature of the oscillations, as might be suspected on purely physical grounds. The simplest case occurs when the frequency of the capacitance variation is the same as that of the applied e.m.f., a condition easily produced, for example, by driving the varying condenser from a synchronous motor connected to the source of the applied e.m.f. V. If in addition $\theta_0 = \pi/2$, equation (7) becomes much simplified and may be written as:

$$\frac{d^2Q}{dt^2} + \frac{R}{L}\frac{dQ}{dt} + \omega_0^2 Q = -\left[\frac{V}{L} + \omega_0^2 hQ\right]\cos \alpha t. \qquad (7a)$$

When written in this form, it is easily seen that (7a) also applies to a constant parameter system on which is impressed an e.m.f. whose amplitude is proportional to the displacement. This equation, together with several related ones, has been discussed extensively in a recent monograph by Pedersen,[11] who has there demonstrated the possibility of the existence

[11] P. O. Pedersen, "Sub-harmonics in Forced Oscillations in Dissipative Systems," Copenhagen Danmarks Naturvidenskabelige Samfund (1933).

of sub-harmonic currents (i.e. currents, the frequency of which is a sub-multiple of the frequency of the impressed e.m.f.). It follows that sub-harmonics may also be produced in systems having periodically varying capacitive or inductive elements. It is to be expected that varying parameter circuits have other unusual characteristics, as indicated by the nature of their natural and spontaneous oscillations. For instance, the reduction of the total damping of the circuit for certain adjustments presages a sharpening of the response curve of current dQ/dt vs. frequency $\nu/2\pi$, and the Fourier series portion of the solution for the natural oscillations indicates a series of humps to this response curve. That these predictions are actually fulfilled will be shown below.

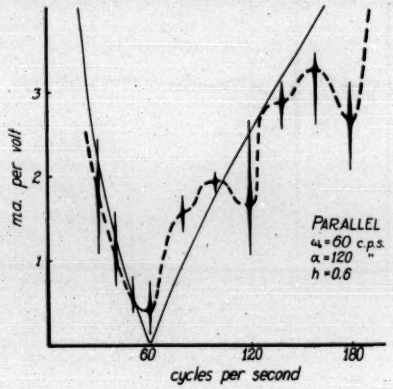
Experimental Results.

In the general case, equation (7), the frequency $\alpha/2\pi$ of the capacitance variation may bear any ratio to the frequency $\nu/2\pi$ of the applied e.m.f. Solutions for the steady state charge and current could be found for a given set of values of the parameters, but this is not advisable because of the large amount of work required. Therefore, the experimental work described below was carried out in order to illustrate the general behavior of the system for various values of the ratio ν/α.

If the frequency of the impressed sinusoidal e.m.f. is given successively different values from zero up to a certain value and the current plotted as a function of this frequency, the response curve of the circuit * is obtained. The dotted curve of Fig. 9 shows an experimentally measured response curve of r.m.s. current vs. frequency $\nu/2\pi$ for the parallel circuit of Fig. 1*d* for the conditions: $\alpha/2\pi = 120$ c.p.s.; $\omega_0/2\pi = 60$ c.p.s.; and $h = \frac{1}{2}$. The solid curve shows the familiar resonance curve for the constant parameter case, that is, for $h = 0$. Pronounced differences appear between the response of the constant parameter circuit and that of

* The condenser variation function was here of square wave form, instead of sinusoidal, and was produced by commutating two fixed condensers. A loss of energy resulted, preventing spontaneous oscillation, but this did not materially influence the circuit behavior.

FIG. 9.



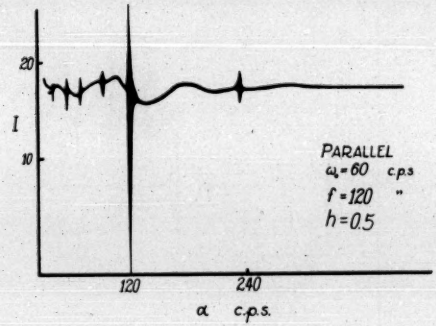
The quasi resonance curve (dotted) for the circuit of Fig. 1*d*, determined experimentally for the conditions $\alpha = 2\pi . 120 = 2 . \omega_0$, $h = 0.6$, and R sufficiently large to prevent spontaneous oscillations. The solid line curve is the ordinary resonance curve for $h = 0$.

the periodically varying parameter one. A very peculiar phenomenon occurs at the frequencies:

$$\frac{\nu}{2\pi} = \cdots, 30, 40, 50, 60, 80, 100, 120, 140, 160, 180, \cdots.$$

If the frequency $\nu/2\pi$ is slowly changed so as to approach one of these frequencies, say ν_0, the current amplitude waxes and wanes with increasing magnitude but more and more slowly, very much in the manner of beats, until exact synchronism between ν and ν_0 obtains. For exact synchronism, the current is constant and substantially sinusoidal; but it depends on the phase θ_0 between ν and α, and it can be varied over wide limits by this means alone, as indicated by the vertical extension of the curves. This unusual behavior of the circuit will be termed *quasi-resonance*. The response of the circuit at a quasi resonant frequency is thus inherently a function of the phase angle between the applied e.m.f. and the parameter variation. A curve showing this dependency of current on

FIG. 10.

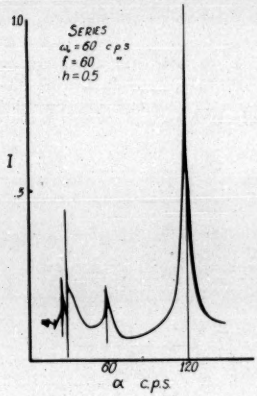


Similar to Fig. 9 except that the rate of variation α is the independent variable.

phase will be referred to as the quasi-resonant *phase response* of the circuit. These phenomena are also to be seen in the curve of Fig. 10, where the rate of condenser variation $\alpha/2\pi$ has been taken as the independent variable. The relatively large extent of the phase response for $\nu = \alpha$ is again observable. The curve of Fig. 11 is for the series connection 1*a*, and it too displays this strong quasi resonant behavior. The three curves for the varying capacitance circuit reproduced here do indeed bear out the predictions of the foregoing paragraph.

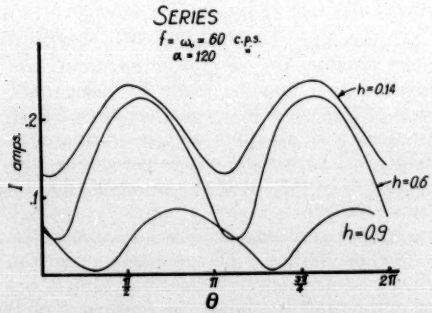
The quasi resonant phase response of the series connection 1*a* for the conditions $\nu = \omega_0 = 60.2\pi$, $\alpha = 2\omega_0 = 120.2\pi$, $h = 0.14$, 0.6, and 0.9 is shown in detail in Fig. 12. As θ_0 is continuously varied, the current changes in magnitude, going smoothly through two maxima and minima in 2π radians. The height and shape of the phase response curves depend, among other things, on the value of h. As h increases the ratio of the maximum to the minimum current becomes larger and for $h = 0.9$ it may be seen from the figure that the current can be varied in a ratio of more than ten to one.

FIG. 11.



Similar to Fig. 10 except that the circuit is that of Fig. 1a.

FIG. 12.



The quasi resonant phase response for the circuit of Fig. 1a. I is the r.m.s. current through the circuit and θ is the phase angle between α and the applied e.m.f. of frequency $f = 2\alpha = \omega_0$.

Mathematical Analysis.

An analytical solution for the differential equation (7), with the limitations that ν/α be a rational number and that only stable oscillations exist, may be found by assuming the

charge to be expressible as a Fourier series. For the case $\nu = \omega_0$ and $\alpha = 2\nu$ we would assume:

$$Q = \sum_{n=0}^{\infty} (a_n \cos n\nu t + b_n \sin n\nu t). \tag{8}$$

The recurrence relationships are found to be given by:

$$\begin{aligned} &a_n\left[-n^2 + n\left(1 - \frac{R}{\nu L}\right) + 1\right] \\ &\qquad + \frac{1}{2}h(a_{n+2} + a_{n-2}) \begin{cases} = 0 & \text{for } n \neq 1, \\ = \dfrac{V}{L}\sin\theta_0 & \text{for } n = 1, \end{cases} \\ &b_n\left[-n^2 + n\left(1 + \frac{R}{\nu L}\right) + 1\right] \\ &\qquad + \frac{1}{2}h(b_{n+2} + b_{n-2}) \begin{cases} = 0 & \text{for } n \neq 1, \\ = \dfrac{V}{L}\cos\theta_0 & \text{for } n = 1. \end{cases} \end{aligned} \tag{9}$$

A formal solution may be obtained with the help of either infinite determinants or of continued fractions. Or, an approximate solution may be made by using only the first several terms of (8), as Pedersen has done. All of these methods are long and laborious, and, in addition, an auxiliary investigation must be carried out to determine whether subharmonics exist. In this case, (8) is not of the proper form, hence it must be replaced by a series beginning with the frequency $\nu/2.2\pi$.*

The following method † of successive approximations is not only much easier to carry out, but also it has the advantage of automatically giving the frequency of the lowest component present. An accuracy well within practical requirements may be readily secured. The case of $\nu = \omega_0$,

* Reference to Pedersen's monograph may be made by the interested reader.

† A somewhat similar method is mentioned in Whittaker and Watson, "Modern Analysis," p. 420, in connection with the characteristic values of the homogeneous equation (1).

$\alpha = 2\nu$ will again be used for illustration. A solution of the form:

$$Q = Q_1 + Q_2 + Q_3 + \cdots \tag{10}$$

will be sought, where the Q_1, Q_2, $\cdots$ are successive approximations determined as shown below. It is expected that the principal component of the charge will have a sinusodal oscillation with the frequency $\nu/2\pi$ of the impressed e.m.f., hence the first approximation will be assumed to have the form:

$$Q_1 = q_1 \cos(\nu t + \theta_1), \tag{11}$$

where q_1 and θ_1 are coefficients to be determined later. When Q_1 is substituted in (7), the equation is not satisfied, the non-homogeneous term:

$$V_1 = -q_1\nu R \sin(\nu t + \theta_1) + q_1\nu L\left\{\frac{\nu h}{2}\cos(3\nu t + \theta_1) + \cos(\nu t - \theta_1)\right\} \tag{12}$$

being the remainder. The discrepancy lies in the term of frequency $3\nu/2\pi$, hence the second approximation Q_2 must be sinusoidal with this frequency, i.e.:

$$Q_2 = q_2 \cos(3\nu t + \theta_2) \tag{13}$$

and the coefficients q_2 and θ_2 are determined so that no term in 3ν appears in the remainder when $Q_1 + Q_2$ is substituted in the differential equation. The substitution of Q_2 in (7) gives rise to the non-homogeneous remainder:

$$V_2 = -q_2\nu^2\sqrt{(8\nu L)^2 + (3R)^2}\sin(3\nu t + \theta_2 + \varphi_3) + q_2\frac{\nu^2 hL}{2}[\cos(5\nu t + \theta_2) + \cos(\nu t - \theta_2)], \tag{14}$$

where:

$$\varphi_3 = \tan^{-1}\left(\frac{-8\nu L}{3R}\right),$$

containing the desired frequency $3\nu/2\pi$ and also the unwanted frequency $5\nu/2\pi$. From (12) and (14), it may be seen that no term in 3ν appears in $V_1 + V_2$ provided q_2 and

θ_2 satisfy the conditional equations:

$$q_2\sqrt{(8\nu L)^2 + (3R)^2} = q_1\frac{\nu hL}{2},$$
$$\sin(3\nu t + \theta_2 + \varphi_3) = \cos(3\nu t + \theta_1). \tag{15}$$

When these equations are satisfied, the approximate solution is given by:

$$Q_1 + Q_2 = q_1\nu\left[\cos(\nu t + \theta_1) + \frac{\nu hL}{2\sqrt{(8\nu L)^2 + (3R)^2}}\cos(3\nu t + \theta_2)\right] \tag{16}$$

and the remainder is:

$$V_1 + V_2 = q_1\nu\left[-R\sin(\nu t + \theta_1) + \frac{\nu hL}{2}\cos(\nu t + \theta_1) + \frac{(\nu hL)^2}{4\sqrt{(8\nu L)^2 + (3R)^2}} \times \left(\cos\left(\nu t - \theta_1 - \frac{\pi}{2} + \varphi_3\right) + \cos\left(5\nu t + \theta_1 + \frac{\pi}{2} - \varphi_3\right)\right)\right]. \tag{17}$$

The next approximation would be $Q_3 = q_3\cos(5\nu t + \theta_3)$ and q_3, θ_3 given such values that the fifth harmonic term would cancel in $V_1 + V_2 + V_3$, etc. This process can be continued until the required degree of precision has been obtained. Comparing V_1 with $V_1 + V_2$ shows that the remainder is not too far from the correct value of $V\sin(\nu t + \theta_0)$, and that with only two terms. The convergence is generally rapid enough for any practical purpose. The absolute convergence of the series has been proven [3] and therefore the infinite series $Q_1 + Q_2 + Q_3, \cdots$ is an exact solution of the differential equation. The mechanics of evaluating the constants q_n, θ_n can be simplified by setting up the two following series: Series A, for the solution having the two undetermined coefficients q_1, θ_1; and series B, containing only terms of frequency $\nu/2\pi$ (this series also contains q_1, θ_1). Series B

represents the right hand side of an equation of form (7) which would have series A as a solution. Series B converges to the proper e.m.f. $V \sin(\nu t + \theta_0)$, and it is used to determine the constants q_1 and θ_1 and thence all the constants of the first series. The construction of a chart for the several terms in both series also greatly shortens the labor of computation.[3] Written in terms of these two series, the solution may be expressed as:

$$Q = q_1\Big[\cos(\nu t + \theta_1) + \frac{\nu hL}{2\sqrt{(8\nu L)^2 + (3R)^2}} \times \cos\Big(3\nu t + \theta_1 + \frac{\pi}{2} - \varphi_3\Big) + \cdots\Big], \quad (18)$$

where:

$$q_1 = \frac{-V}{\nu R\sqrt{A^2 + B^2}}, \qquad \theta_0 = \tan^{-1}\frac{B}{A},$$

$$A = \cos\theta_1 - \frac{\nu hL}{2R}\sin\theta_1 - \frac{(\nu hL)^2}{4R\sqrt{(8\nu L)^2 + (3R)^2}}\sin\Big(\theta_1 + \frac{\pi}{2} - \varphi_3\Big) - \cdots,$$

$$B = \sin\theta_1 - \frac{\nu hL}{2R}\cos\theta_1 - \frac{(\nu hL)^2}{4R\sqrt{(8\nu L)^2 + (3R)^2}}\cos\Big(\theta_1 + \frac{\pi}{2} - \varphi_3\Big) - \cdots.$$

Although the case where $\alpha = 2\nu$ has been studied in most detail, the method above may be used with equal facility where $n\alpha = \nu$ or $\alpha = n\nu$, n an integer. For example, when $\nu = \alpha = \omega_0$ one finds:

$$Q = q_1\Big[-\frac{h}{2}\cos\theta_1 + \cos(\nu t + \theta_1) + \frac{\nu hL}{2\sqrt{(3\nu L)^2 + (2R)^2}}\cos(2\nu t + \theta_2) + \cdots\Big], \quad (19)$$

where

$$q_1 = \frac{-V}{\nu R\sqrt{A^2 + B^2}}, \qquad \theta_0 = \tan^{-1}\frac{B}{A},$$

$$A = \cos\theta_1 - \frac{(\nu hL)^2}{4R\sqrt{(3\nu L)^2 + (2R)^2}}\sin\theta_2 + \cdots,$$

$$B = \sin\theta_1 + \frac{\nu h^2 L}{2R}\cos\theta_1 - \frac{(\nu hL)^2}{4R\sqrt{(3\nu L)^2 + (2R)^2}}\cos\theta_2 + \cdots,$$

$$\theta_2 = \theta_1 + \frac{\pi}{2} + \tan^{-1}\left(\frac{-3\nu L}{R}\right).$$

The results of some of the numerical computations are shown in Figs. 13, 14 and 15, where the small circles represent computed values of charge and the small squares denote computed values of current, all computations having been carried out to three significant figures. These curves will be discussed in the next section.

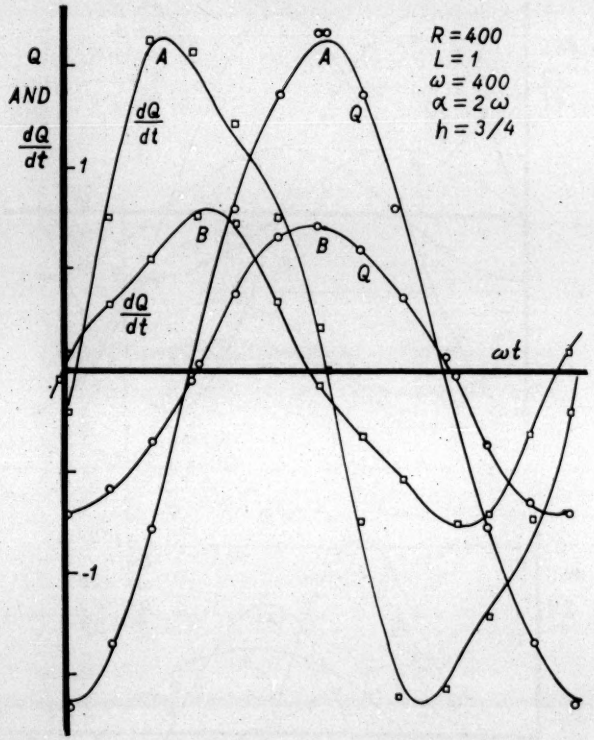
Differential Analyzer Solutions.

In order to have another solution, independently arrived at, the M. I. T. Differential Analyzer [7] was used to obtain the steady state solution of (7). The initial conditions at $t = -\theta_0$ were calculated by the above method and several cycles run off on the machine. It is certain that any transient, if present, was entirely inappreciable. It is worth comment that for both the homogeneous and non-homogeneous cases the set-up of the Differential Analyzer was entirely automatic, and it was only necessary, once the adjustments for parametric values and initial conditions were made, to start and stop the machine in order to secure the appropriate solution. The results are reproduced in Figs. 13, 14 and 15 as solid curves. The agreement between these machine solutions and the solutions computed by the method of successive approximations is quite good and furnishes a mutual check on the correctness of the two methods. It may be concluded that the method of successive approximations developed here for computing the steady state behavior of these types of varying parameter circuits is both practical and accurate.

The Quasi Resonant Phase Response.

The variation of current with the phase angle θ_0, as shown in the experimental curves of Fig. 12, has already been commented on. This phenomenon may also be seen in the

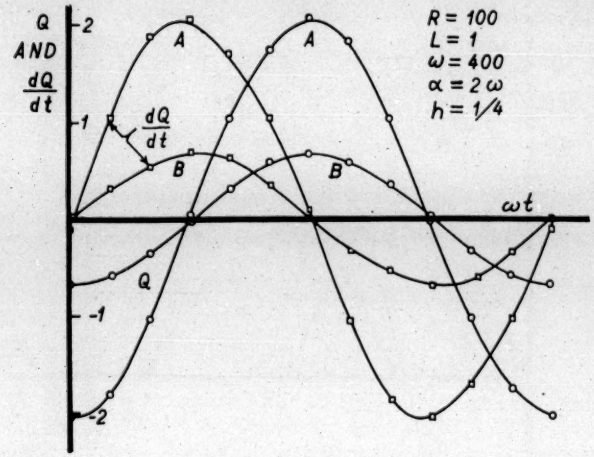
FIG. 13.



Instantaneous values of the steady state current dQ/dt and charge Q in the circuit of Fig. 1a. Solid curves are from the Differential Analyzer; circles and squares indicate values computed by the method of successive approximations. These curves are obtained for a value of voltage V which will make both $Q_{max.}$ and $I_{max.}$ equal to unity for $h = 0$. In curves A, $\theta = 45.45°$ and in B, $\theta = 135.14°$.

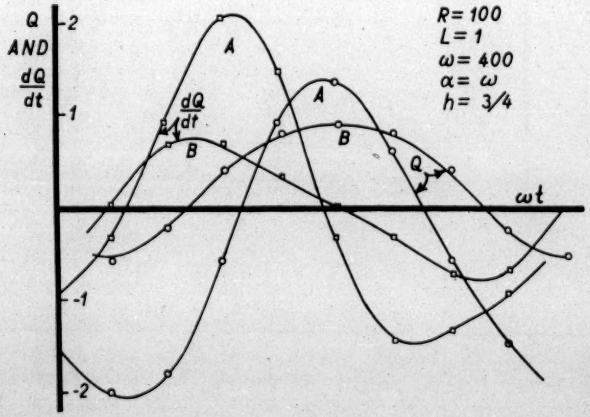
calculated curves of Figs. 13, 14 and 15. Since the charge amplitude varies with θ_0 as $1/\sqrt{A^2 + B^2}$, as seen from expressions (18) and (19), curves showing the relation between these two quantities will form an analytical presentation of

FIG. 14.



Similar to Fig. 13, but for different conditions as noted on curves, and: $A, \theta = 45.17°$; $B, \theta = 134.8°$.

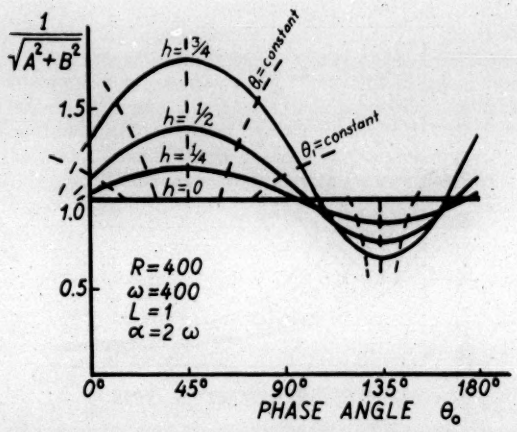
FIG. 15.



Similar to Fig. 13, but for different conditions as noted on curves, and: $A, \theta = 42.71°$; $B, \theta = 174.6°$.

this current variation phenomenon. Computed curves of this relationship are reproduced in Fig. 16. They show clearly how the current varies over a considerable range with a change in the phase angle between the applied e.m.f. and the varying condenser. This variation is a manifestation of the transfer of energy through the varying condenser from the mechanical

FIG. 16.



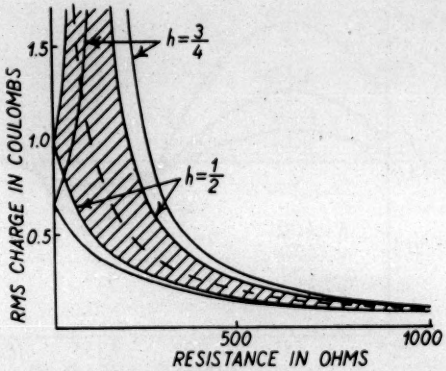
Theoretical curves of the quasi resonant phase response. The charge Q is proportional to $1/\sqrt{A^2 + B^2}$. Compare these calculated curves with the experimental ones of Fig. 12.

to the electrical system, or vice versa. For certain phase angles, the varying condenser acts as a generator, converting mechanical energy to electrical and decreasing the current, while for other phase angles it acts as a motor, taking energy in electrical form from the circuit and doing mechanical work on the external system.

The *magnitude* of the variation of charge and of current with θ_0 depends on $R/\nu L$ and h. The diagram of Fig. 17 illustrates this dependency. The region in which the r.m.s. value of charge varies as a function of the phase angle is here represented by the shaded area for the value of $h = \frac{1}{2}$. The dotted line shows the r.m.s. charge for $h = 0$, and, when

$h = \frac{3}{4}$, the boundaries of the shaded area extend to the correspondingly marked lines. Clearly, as R is increased the variation becomes very small. It also appears that, for very small values of R, the variation again decreases, but this condition is accompanied by instability and the present analysis represents but a part of the total solution. In fact, it must be remembered that in a practical case the rate of

FIG. 17.



Theoretical diagram of the extent of the variation of charge with the resistance. For a given value of resistance the charge amplitude can be varied vertically within the shaded region by a change in phase angle θ. The extent of the variation becomes very small as R increases.

capacitance variation α must be held exactly constant in order to secure the large current changes here indicated, which in turn may require an unrealizable energy source for varying the condenser.

The experimentally observed waxing and waning of the r.m.s. current for slightly non-synchronous ratios of α and ν is now easily explained as the result of a continuously changing phase angle between these two quantities, causing the current periodically to go through the entire range of values appropriate to the particular adjustment.

Although the particular case of $\alpha = 2\nu$ has been used as an illustration in the above paragraphs, similar quasi-resonant

phenomena occur whenever the motive force and capacitance variation are synchronized with $\nu/\alpha = n$ or $1/n$, n an integer, but the magnitude of the maximum current change becomes less as $\alpha = 2\nu$ is departed from, a fact directly explainable on the basis of energy transfer.

This quasi resonant characteristic of varying parameter circuits, viz. the dependence of the current upon the phase relation between the parameter variation and a synchronized e.m.f., does not appear to have been observed previously. Many interesting applications can be thought of, such as the following: measurement of the phase displacement of two currents or of a current and a synchronized mechanical motion, such as the "power angle" of a synchronous generator; stabilization of the speed of a d.-c. motor could be realized by attaching a commutator to its shaft and employing the above described current variation to control the torque and speed; a continuously variable current or voltage regulator having high efficiency.

The Farmer and the Ice Well.—According to the U. S. Bureau of Dairy Industry, the ice well method of cooling and holding cream on dairy farms proved a good investment in the Northern Great Plains area this last summer. To construct an ice well, a hole approximately 9 feet square and 9½ feet deep is dug on a well-drained location convenient to the milk room and the water supply. Small to medium sized stones are set in the bottom to a depth of 1½ feet. Two by four studding are placed 2 feet apart against the earth walls. Cheap unmatched lumber nailed to the studding gives an ice storage space approximately 8 feet square and 8 feet deep. A small structure is built over the well, the floor in sections to facilitate removal, to allow free circulation of cold air when freezing the ice block in winter.

On the arrival of cold weather, water is sprinkled on the stones until a solid bottom of ice gradually freezes in the well. Snow and water may be used at the start if snow is available. Freezing the bottom of the ice chamber cannot be rushed as adding too much water at one time will melt the thin layer of ice in the bottom and allow the water to escape through the stones. Adding the water in thin layers and frequently on good freezing days and nights gives the most satisfactory results.

A 6½ foot block of ice in the well will leave room for a 5-gallon cream can between the top of the block and the floor. Experience shows that an ice well, opened for use in May, will last well into September or October.

C.

"A car with an eight-cylinder engine running 50 miles an hour touches off 10,000 fires every minute, or 600,000 in an hour."—T. A. Boyd, "Research."

A MODIFIED TECHNIQUE FOR THE KJELDAHL PROCEDURE.

BY

ABRAHAM HENWOOD, Sc.D., and RAYMOND M. GAREY, B.S.

By reason of its adaptability to a wide range of materials and the simplicity of its operations, the Kjeldahl Procedure has displaced all others for the determination of amino and cyanide nitrogen. It finds constant application in biochemical research and clinical analysis and also in the analysis of foodstuffs and fertilizers.

In the biochemical field micro methods have come into common use. While these methods almost necessarily involve some sacrifice of precision, they are indispensable because of the small quantities of materials often available for analysis and the need for accumulating large masses of data with the minimum expenditure of time and effort.

In the analysis of foodstuffs and fertilizers, however, there is usually no dearth of material and it has become the habit to require a degree of precision comparable with that obtaining in mineral analysis. As a consequence macro methods continue to hold sway in this field.

The technique of the macro procedure, while simple, is attended with a number of inconvenient features. Among these may be mentioned the following:

(1) The escape of sulphuric acid mist throughout the digestion, necessitating the installation of cumbrous, costly and often inefficient devices for collecting this very corrosive mist and thus preventing its condensation on laboratory fittings and furniture, to say nothing of the respiratory tract of the operator.

(2) The foaming, often prolonged, which accompanies the digestion of materials containing large proportions of water, as, e.g., milk.

(3) The length of time needed to complete the digestion, frequently two hours or longer.

(4) The complication of the apparatus with glass traps

designed to prevent the passage of alkali spray into the condensate, in the process of distilling off the ammonia.

(5) The condensing system, requiring running water, sinks and more or less pipe fitting.

(6) The unnecessarily large quantities of materials required, viz: the material being analyzed, sulphuric acid, potassium sulphate, sometimes sodium sulphide, sodium hydroxide, standard acid and alkali, etc.

To ameliorate or remove these inconvenient features we submit the following modifications and innovations:

Some time ago we published [1] an account of a device for the prevention of the escape of sulphuric acid mist from the digestion flask, so that it became possible to carry out a macro digestion on the laboratory table, with no inconvenience or harmful results. This meets objection (1).

As is well known in the digestion of materials containing large proportions of water, as for example milk, etc., large quantities of water must be evaporated before the digestion can be completed; moreover this water or the steam formed from it causes very annoying foaming during the digestion. This difficulty is entirely obviated by the use of "oleum" instead of ordinary sulphuric acid. This meets objection (2).

In 1931 Lauro [2] noted the remarkable effect on the time of digestion which results from the addition of a small quantity of selenium. The time required for the digestion is virtually reduced from hours to minutes.

The following observations indicate the manner in which the selenium functions. If selenium be heated with concentrated sulphuric acid, it dissolves, giving an olive green solution, which on continued heating begins to evolve sulphur dioxide gas, the solution becoming colorless. Obviously the sulphuric acid has oxidized the selenium, presumably to selenious acid. This solution when used in a Kjeldahl digestion acts with extreme rapidity, the digest becoming colorless in less than half an hour, with the volatilization of elementary selenium. Evidently selenious acid oxidizes organic matter more actively than does sulphuric acid. This explanation of the action of selenium is further substantiated by the fact

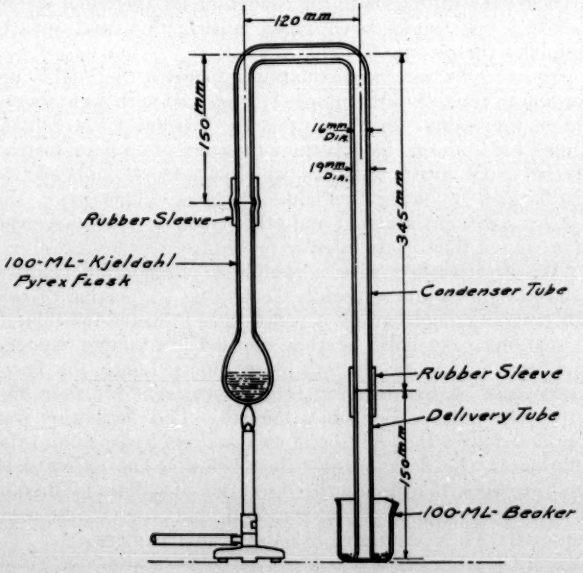
[1] *Science*, 76, 1979 (Dec. 2, 1932), 524.

[2] *Jour. Ind. and Eng. Chem.*, Analytical Edition, 2-4 (Oct. 15, 1931), 401.

that the rapidity with which the digestion is completed is made even more rapid when the quantity of selenium or of selenious acid employed in the digestion is increased. This addition of selenium overcomes objection (3).

We have found it possible to dispense with the spray trap by making the exit tube from the distillation flask of the same diameter as the neck of the flask, thus avoiding acceleration of the speed of the spray particles consequent on passing through tubes of smaller diameter and further by making the vertical distance from the boiling liquid in the flask to the horizontal tube leading to the condenser great enough to afford opportunity for any ascending spray particles to lose their speed before reaching the horizontal tube.

To determine how effectively this arrangement accomplished the desired result we placed about two grams of sodium hydroxide in 50 mls. of water in a 100 ml. kjeldahl flask and distilled with our assembled apparatus (see fig.) into



10 mls. of distilled water to which phenolphthalein had been added. No indication of alkalinity was shown in the distillate after 15 minutes brisk boiling. We further conducted the following experiments to test this point:

Mls. NaOH Solution.	Mls. HCl Solution. 0.01986 N.	Mls. HCl/Mls. NaOH.
10.45	10.00	0.957
16.31	15.50	0.950
10.58	10.03	0.949
10.30	9.80	0.951

In the last two cases the acid was attached to the distilling apparatus, a solution of sodium hydroxide (1 gram in 50 mls. of water) being placed in the distilling flask. We distilled for 15 minutes before titrating with the standard sodium hydroxide solution. The results show that the alkaline spray carried over under conditions of an actual determination is negligible.

The substitution of an air condenser for the usual water-jacketed one works with entire satisfaction and greatly simplifies the set-up.

In order to test the distillation apparatus thoroughly according to the technique adopted we worked with a number of ammonium salts. In these cases the distillations were continued for from one-half to three-quarters of an hour instead of the usual fifteen minutes which we found sufficient in distillations following kjeldahl digestions. This made the test for spray entrainment and other errors of operation even more severe than in the regular procedure.

We first worked with a sample of ammonium chloride marked Ammonium Chloride, Technical. A portion of this salt weighing 0.9984 grams was dissolved in water and diluted to 500 mls. 50 mls. of this solution containing 0.09984 $\pm$ 0.00002 grams of the salt were pipetted into the flask. 100.00 mls. of hydrochloric acid (0.019860 $\times$ N) were run into a 250 ml. beaker from a burette. The distillation was conducted after the addition of solid sodium hydroxide to the solution in the flask as described below. The excess acid was titrated with a standardized solution of sodium hydroxide (1 ml. = 0.9560 mls. of the standard acid). 7.13 mls. were required. These data give 25.95 per cent. nitrogen.

A second aliquot from the same solution in which 99.96 mls. of standard acid were used and 6.84 mls. of standard alkali were required to neutralize the solution gave 26.01 per cent. nitrogen.

If we admit possible errors in the observed quantities as follows:

$\Delta V = 5. \times 10^{-2}$ where V is the volume of standard acid used,
$\Delta f = 5. \times 10^{-4}$ where f is the standard of the alkali against the acid,
$\Delta v = 5. \times 10^{-2}$ where v is the volume of the standard alkali used,
$\Delta W = 5. \times 10^{-5}$ where W is the mass of salt in the aliquot taken,
$\Delta F = 5. \times 10^{-6}$ where F is the normality factor of the standard acid determined by silver nitrate, weighing silver chloride,

the maximum error in P, the per cent. nitrogen, is 0.05, i.e. two determinations could differ by twice this quantity, or 0.10 from the assumed causes. The two results obtained differ by 0.06. From which we conclude that there were no errors of an operational nature, such as loss of ammonia, incomplete distillation of ammonia, etc., large enough to make the error of a determination greater than what might be expected from the errors of observation.

Four other results on this same sample of ammonium chloride in which a one-tenth aliquot of 0.4993 grams were used gave 25.94, 26.06, 25.87 and 25.75. The maximum difference in these results is 0.31. The maximum allowed by the assumed errors of observation is also 0.31, so that the actual difference in these results is no greater than could occasionally occur from the errors of observation alone.

Two portions of a sample of ammonium oxalate, one-tenth aliquots of a solution containing 0.6275 grams, each gave 19.54 per cent. nitrogen. If we regard it as established by the previous experiments described, that errors due to lye entrainment are negligible and other operational errors such as ammonia leakage, incomplete volatilization of ammonia, etc., are always in the same direction and therefore unable to compensate each other, and since these operational errors

could scarcely be of the same magnitude in two experiments, we may fairly conclude these errors are of such a magnitude as to be negligible.

Two portions of a sample of ferrous ammonium sulphate gave, operating on one-tenth aliquots of 0.9409 grams, 7.21 and 7.14 per cent. nitrogen. The maximum difference in two results due to the assumed observational errors is 0.06. The actual difference in the two results in 0.07.

It appears that we may fairly conclude that the distillation conducted as described below with the apparatus shown in the figure is not infected with operational errors of moment in comparison with the maximum errors inherent in careful observations.

Consideration of the above facts and the desire to simplify the procedure in this extremely useful method without any radical changes in technique, suggested the following: Use a 100 ml. pyrex kjeldahl flask for the digestion and the distillation; use one-tenth of the quantities of materials employed in the regular macro procedure; use one-fiftieth normal acid and base for absorbing the ammonia and titrating the excess acid. These changes make the procedure very much neater and more expeditious, without any material sacrifice of precision.

We give the steps of the procedure in detail and in serial order.

(1) Clean and dry a 100 ml. pyrex kjeldahl flask.

(2) Weigh 0.1000 grams flour or the equivalent amount with respect to nitrogen of any other material under examination, not, however, using less than 0.05 gm. Transfer this to the dry flask, without loss, with the aid of a small fragment of filter paper, finally adding the piece of filter paper to the flask. (Under no circumstances should a camel's hair brush be used for this purpose as particles of hair are almost sure to get into the flask and vitiate the analysis.) (Liquids may be weighed and introduced in small glass bulbs.)

(3) Weigh roughly or measure 1 to 1.5 grams pure potassium sulphate and transfer to the flask.

(4) Add to the flask a small fragment of selenium weighing approximately 0.01 grams.

(5) Add a "boiling granule" to ensure smooth boiling.

(6) Measure into the flask 2.5 mls. of concentrated sulphuric acid or "oleum" according as the material being analyzed is dry or contains much water as, for example, milk.

(7) Insert the porous tube [3] fitted with its paper tape in the mouth of the flask and proceed with the digestion, using a bunsen flame about one-half inch high, touching the bottom of the flask. The flask is supported in the usual inclined position by a clamp applied at the neck.

(8) The digestion should be conducted with a degree of caution until streams of oily condensate of sulphuric acid are seen running back just above the body of the acid. It may then be conducted with more speed. The liquid will be colorless and the walls of the flask perfectly clean in about ten minutes.

(9) Remove the porous tube (which will be seen to have acquired a slight sublimate of red selenium which may be removed when desired by heating to redness in a bunsen flame).

(10) Add about 35 mls. of water to the contents of the flask, adding the first portions very carefully, drop by drop, down the wall of the flask.

(11) Mix the contents of the flask by twirling gently and then cool somewhat, either by allowing to stand a few minutes or by running tap water on the outside of the flask.

(12) Mount the flask in the clamp in a vertical position.

(13) Bring the air condenser into position by means of a second clamp operating on the same stand.

(14) Deliver into a 100 ml. beaker an accurately measured quantity (10.00 mls. or if nitrogen is exceptionally high, 15.00 mls.) of 1/50 normal acid (hydrochloric or sulphuric).

(15) Attach the delivery tube to the air condenser by means of the rubber sleeve. Place the beaker beneath the delivery tube.

(16) Add about 3 grams of sodium hydroxide (either in the form of pellets or a fragment cut from a stick), sliding it into the flask quickly. Connect the condensing system without undue delay by means of the rubber sleeve.

(17) Twirl the flask gently to dissolve the sodium hydroxide and mix the solution.

[3] *Science*, loc. cit.

(18) Distil over a low bunsen flame about one-half inch high just touching the bottom of the flask, for ten or fifteen minutes. The air condenser should be hot about one-half way down the vertical limb leading to the beaker. (See figure.)

(19) Disconnect the delivery tube from the condenser, leaving the delivery tube in the beaker.

(20) Push the burner from beneath the flask.

(21) Titrate the excess acid with 1/50 normal sodium hydroxide, using 10 drops of a saturated, freshly prepared aqueous solution of methyl red as indicator. Titrate until water white, pH 6.1. The end point is extremely sharp though the tint is faint. There is no difficulty in locating the end point to within a fraction of a drop. The delivery tube which remains in the beaker during the titration is used as a stirrer. No water is used to rinse during the titration as it is not desirable to lighten the already faint tint of the indicator by unnecessary dilution.

The results which are recorded below were obtained by following the above procedure.

Four analyses on 0.1000 gram samples of flour gave 13.71, 13.67, 13.69 and 13.66 per cent. protein.

Three analyses on 0.468, 0.414 and 0.342 gram of milk, respectively, gave 3.27, 3.28 and 3.34 per cent. protein.

Glutamic acid marked C. P. gave in two analyses on 0.0283 gram and 0.0267 gram, respectively, 9.44 and 9.49 per cent. nitrogen. Theory requires 9.52 per cent.

Commercial "Plant Food" (Label Analysis gave N = 4.00 per cent.). Two samples of 0.0492 and 0.0571, gave 3.94 and 3.94 per cent. nitrogen.

Four samples of Cuban tobacco working on samples of 0.1000 gram gave 3.95, 4.07, 3.95 and 3.92 per cent. nitrogen.

These results are sufficient to show the accuracy of the procedure. On the side of convenience and economy of time it seems very much to be preferred to the usual macro method. Two Kjeldahl determinations can be completed in about an hour without undue haste.

CENTRAL HIGH SCHOOL,
PHILADELPHIA,
August, 1935.

GUIDE FOR CRYSTAL DRAWING.

BY

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INTRODUCTION.

In publications of methods for crystal drawing from the gnomonic projection, there are no directions given in such detail that a beginning student in crystallography can interpret them independently. The directions given in this paper are intended to be so specific that they may serve that purpose.

DISCUSSION.

In a study of the crystalline form of organic and inorganic compounds one of the important interpretations of the results, aside from measurement of and classification into crystal system, is an exact drawing of the crystal. Drawings made directly from the gnomonic projection, and relying upon the symmetry of any particular crystal system for proportional development of the faces, give the ideal crystal. However, a drawing of the typical crystal, giving faces with the distortions as they actually occur, is dependent upon the personal judgment of the individual worker and, therefore, the accuracy of the drawing may vary in each case. The camera lucida attached to a stereoscopic microscope focused on the crystal in a certain position, permits a tracing to be made of the edges between the various faces on the crystal, and this sketch is used as the basis of the orthogonal drawing as it is made from the gnomonic projection. For a detailed account of this procedure the reader is referred to the article "Use of the Camera Lucida in Crystal Drawing" by McNabb and McNabb (1). Further examples of crystal drawings made by this method may be found in the article by McNabb and Alsentzer (2), "The Crystalline Form of Some Cobaltammines of the Dinitro Series."

The directions for crystal drawing, as given herein, may

be used exactly as given, for crystals belonging to the cubic, tetragonal, hexagonal and orthorhombic systems. However, in a gnomonic projection of a monoclinic or triclinic crystal, the axis of the crystal is not parallel to the axis of the gnomonic projection. It is necessary either to recalculate the angle measurements in such a way as to throw the inclined axis parallel to the gnomonic projection, or to mount the crystal on the goniometer with the c axis in such a position that the basal pinacoid reading is 0°. The angle measurements obtained in this position are then plotted on the gnomonic projection sheet and the drawings made in the usual way. An example of a monoclinic crystal drawn in this manner is found in the paper by McNabb and Alsentzer (2), page 299, Fig. 2.

It is advisable to use printed charts (obtainable from Oxford Univ. Press) for plotting the gnomonic projection. The printed graduated circle does not represent the circle of projection. It is drawn with a 10 cm. radius so as to insure greater accuracy in marking off φ values. In plotting the ρ values the linear distance (5 times nat. tan. ρ) corresponding to the angular ρ reading of each face is found with a pair of dividers from a horizontal scale printed at the top of the chart.

The normal from a face on the bottom of the crystal is a line perpendicular to the surface of the face, extending through the center of the crystal, through the opposite face of the same form on the top of the crystal, on to pierce the plane of the gnomonic projection, where it is designated as the pole point. Thus, the pole points of these two faces are one and the same. For example, in Fig. *C*, face pole 1 on the chart may also be designated ② as it coincides with the pole point of face ② on the bottom. Faces 1, ①, 2, ②, are all the same form. Likewise 2 = ①, 4 = ③, 3 = ④. Goniometric measurements may be plotted separately for the top and bottom of the crystal, but this is not necessary if the same faces are developed on the top and bottom of the crystal. And, obviously, the prism and pinacoid faces are the same for the top and bottom.

If the student desires to make practice drawings, angle observations may be obtained from the Winkeltabellen and

plotted on a gnomonic projection sheet. The symmetry of the ideal crystal must then be used to determine the proportional development of the faces. If it is possible to obtain a crystal of the substance for which measurements are thus selected, a camera lucida drawing can be made, and then knowledge of the symmetry of the crystal is not necessary. The tables of data on crystal measurement given in the papers by McNabb and McNabb (1) and by McNabb and Alsentzer (2) are also recommended for this purpose. These suggestions are intended for the student who is unable to make his own goniometric measurements. A series of papers edited by Edgar T. Wherry and Charles Palache entitled "The Goldschmidt Two-circle Method" and reprinted from the *American Mineralogist*, Vol. 5, nos. 2–12, 1920, will be found most useful to the beginner.

DETAILED PROCEDURE FOR CONSTRUCTION OF A CRYSTAL DRAWING FROM ITS GNOMONIC PROJECTION.

Example: Oxalato tetrammine cobalti chloride crystals.

Given: Measurements and chart, camera lucida drawing or symmetry. Readings of 12 crystals taken on the Goldschmidt two-circle goniometer. Results averaged (Table 1)

TABLE 1.

Oxalato tetrammine cobalti chloride.

Average readings obtained from measurement of 12 crystals on a Goldschmidt two-circle goniometer.

Face.	Form.	Miller Indices.	Angles Observed.		Angles Calculated.	
			φ.	ρ.	φ.	ρ.
1, 2, ①, ②. . .	*a*	011	0° 13′	32° 44′	0° 00′	32° 41′
3, 4, ③, ④. . .	*c*	101	89 59	44 52	90 00	44 53
5, 8.	*d*	010	0 03	90 01	0 00	90 00
6, 7, 9, 10. . . .	*e*	110	57 06	90 01	57 09	90 00

$p_0 = 0.9963$. $a : b : c = 0.6458 : 1 : 0.6428$.
$q_0 = 0.6428$. Orthorhombic system, bipyramidal class.
Actual size of the crystal drawn: 0.55 mm. greatest diameter.

and plotted on a printed chart (Fig. *C*). For a drawing of the typical crystal, camera lucida drawings of the top and bottom of the crystal are made (Fig. *A*). For the ideal

crystal the proportional development of the edges between the faces is made to correspond to the symmetry of the crystal system.

Method: Construction of edges between faces, or correlation of plotted pole points.

A. Orthogonal Plan (Fig. A).

This procedure gives the directions of all edges on the orthogonal plan, but their proportional development depends on whether the ideal or the typical crystal is to be developed. Figure *A* represents the orthogonal plan, and in this case was originally a camera lucida drawing. (In the text and figures, all bottom faces, or those below the equatorial region of the crystal, have a circle around their designated number.)

Edge between faces 1 and 2. Place the straight edge of a right-angled triangle on an imaginary line *a* passing through the face poles 1 and 2 (see Fig. *C*). A second right-angled triangle is so placed that the line *b* is at right angles to line *a*. The line *b* gives the direction of the edge between faces 1 and 2, and also coincides with the edge as drawn by the camera lucida. This same arrangement of the triangles applies to the corresponding faces ① and ② on the bottom of the crystal.

Edge between faces 1 and 4. Place the straight edge of the triangle simultaneously on face poles 1 and 4 (Fig. *C*). A line at right angles to this is the direction of the edge between faces 1 and 4 (Fig. *A*). The same holds for bottom faces ② and ③.

The same principle of arrangement of the triangles is used in construction of the edges between faces 2 and 3, ① and ④; and between faces 2 and 4 and ① and ③. (Fig. *C* and Fig. *A*.)

Edge between faces 1 and 5. Place the straight edge of the triangle in a direction parallel with that of the face pole 5, in the case of the prism or pinacoid, an arrow passing through the center of the circle (Fig. *C*). The line at right angles is the direction of the edge between 1 and 5 (Fig. *A*). The same position holds for the edge between ② and 5.

The procedure is continued with the same manner of arrangement of the triangles for the construction of the edges

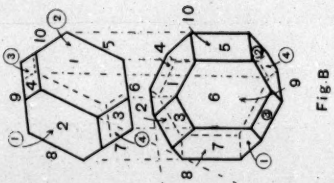
Fig.A
Fig.B

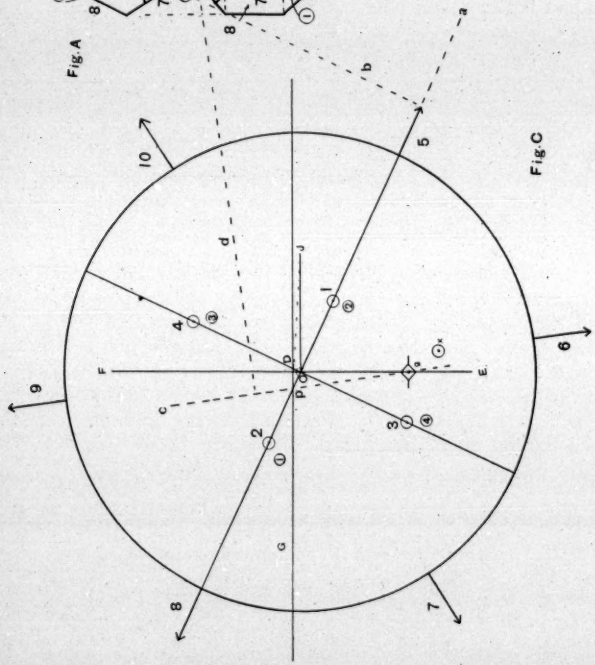
Fig.C
a
b
c
d
E
F
G
J

between faces 2 and 8 and between ① and 8; 3 and 6, ④ and 6; 3 and 7, ④ and 7; 2 and 9, ① and 9; 4 and 9, ③ and 9; 4 and 10, ③ and 10; 1 and 10, ② and 10. Thus, the orthogonal plan is completed.

B. Parallel Perspective (Fig. B).

For the limits of the top of the parallel perspective drawing, construct parallel lines through all points where the edges between top faces meet (Figs. *A* and *B*). These lines are constructed perpendicular to the guide line *G* in Fig. *C*.

If the guide line, as it is provided on the printed chart, happens to pass through or closely to the pole of a face, the face will practically disappear in the perspective drawing. Thus the direction of the guide line must be changed. A guide line *G* (Fig. *C*) is then drawn in the desired position and the angle point *g* found by the following construction. Draw *OJ* parallel to the guide line and *FOE* perpendicular to it, through the center of the circle. With *D* as the center and *DJ* the radius, draw the arc intersecting *OF* at the angle point *g*.

Edge between faces 1 and 2. Place the straight edge of the triangle on face poles 1 and 2 (Fig. *C*). At the point *p* where an imaginary line connecting these poles crosses the guide line *G*, prick with a sharp point. Connect this point with the angle point *g* by a line *c*, and a line *d* at right angles to this gives the direction of the edge between faces 1 and 2 (Fig. *B*). The extent of the edge is determined by the distance between the parallel lines drawn from the points between which the edge between 1 and 2 extends on the orthogonal plan.

The same principle of arrangement of the triangles is used for construction of the edges between the following faces: 1 and 3, 1 and 4, 2 and 3, 2 and 4.

Edge between faces 1 and 6 (Fig. B). Place the straight edge of the triangle in the direction of face pole 6 (arrow, Fig. *C*) and through the center of the circle. Move the triangles in a parallel direction until face pole 1 falls on an imaginary line parallel to that of the first position of the triangle. Prick with a sharp point the place where this line crosses the guide line. Connect this point with the angle point. The direction of the edge is perpendicular to this, and the extent is dependent upon the distance of the edge between

faces 1 and 6 on the orthogonal plan, which is the same as that between the parallel lines extending from the orthogonal plan.

The same procedure is used for the edges between faces 1 and 5, 1 and 10, 2 and 7, 2 and 8, 2 and 9, 3 and 6, 3 and 7, 4 and 9, 4 and 10.

For the bottom of the parallel perspective drawing, construct the parallel lines (within the same boundaries as those from the top of the orthogonal plan to the parallel perspective) between all points where the edges of the bottom faces meet and the guide line. The lines coincide with those drawn from the top faces in cases where edges between prism faces, and between prism and pinacoid faces occur.

Edge between faces ① *and* ② (*Fig. B*). (The procedure is the same as described above for the edge between faces 1 and 2 in the parallel perspective, however, for convenience it is repeated in this case.) Place the straight edge of the triangle on face poles ① and ② (Fig. *C*). At the point where the imaginary line connecting these poles cuts the guide line, prick with a sharp pointed instrument. Connect this point with the angle point and a line at right angles to this gives the direction of the edge between faces ① and ②. The extent of this edge is determined by the distance between the parallel lines drawn from the points between which the edge between 1 and 2 extends on the orthogonal plan. The position in which this first edge of the bottom of the crystal is drawn determines the length of the crystal in the parallel perspective drawing.

The procedure is carried out in a like manner for the edges between the following faces: ① and ③, ① and ④, ① and 7, ① and 8, ① and 9; ② and ③, ② and ④, ② and 5, ② and 6, ② and 10; ③ and 9, ③ and 10; ④ and 7, ④ and 6.

Prism and pinacoid edges coincide with the parallel construction lines. Edges occur between faces 5 and 6, 5 and 10, 9 and 10, 8 and 9, 7 and 8, 6 and 7.

Faces 1, 2, 3, 4 are domes, and they determine the unit distance, since no pyramid face is developed. Assuming a face pole of a unit pyramid to occur at x, the procedure for determining the boundaries of this face, or any other pyramid face, would be the same in principle as that followed for finding the edge between faces 1 and 2.

SUMMARY.

A guide, for student use, is presented for the drawing of a crystal using the gnomonic projection. For artificial crystals, about 0.1 mm. to 1 mm. in diameter, it is recommended that a camera lucida drawing of the top and bottom of the crystal be made, and that this be used as a basis for the orthogonal plan. Using this method, an accurate picture of the typical crystal can be obtained. For an ideal crystal the drawing is made to correspond to the symmetry of the crystal system.

ACKNOWLEDGMENT.

The authors wish to express their appreciation to the Charles Lennig Fund of the Towne Scientific School, University of Pennsylvania, for the purchase of a Goldschmidt two-circle goniometer used for making the crystal measurements published in this paper and in recent papers (1) and (2).

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THIS THING CALLED REASON.

BY

A. A. MERRILL.

I think the people of western civilization are very much deluded as to the part reason can play in life. A large part of education is devoted to those subjects which are supposed to develop the ability to reason logically. We think that if people were only reasonable most of our troubles would disappear. I believe this is an error. As I see it most of our troubles are due to the fact that different people have different standards of what is worth while in life and these standards form their premises from which they start to reason. Starting from different premises, conclusions will be different, no matter how logically we reason. This is why reason could not prevent the great war. The two sides were controlled by leaders who had different standards of what is worth while in life.

Now it happens that the meaning of this difference in standards is well brought out in Einstein's relativity wherein it is shown that "straightness" on one system (path of least effort in vacuo) will be different from "straightness" on another system and therefore physicists on the first system will give a different form to their *picture* of the universe than will physicists on the other system. The *picture* is called by physicists "The geometry of the universe." The difference, of course, is in their local standard of "straightness" not in the universe itself. If you draw a triangle with a parabolic ruler the sum of the angles will not be two right angles. If now you feel sure your ruler is straight, you will feel equally sure that the triangle is non-Euclidean. You see, before we can find Euclidean geometry in physics, we must be sure to start with a Euclidean straight line; but this is just what Nature will not allow physicists to do. In the physical world a Euclidean straight line (not space) can exist only where the density of matter equals zero (see Einstein). Differences in local "straightness" are tied to gravitational

fields. Of course, since everything is warped, no direct instrumental proof of this can be obtained any more than one can get direct instrumental proof of the linear motion of the earth through space (Michelson-Morley experiments) but it is a logical inference from other experiments. The eclipse evidence convinced physicists but personally, long before the publication of Einstein's work, I had drawn this inference from that group of phenomena called "refraction." If we represent the contained volume of a glass lens by X, then ΣL^3 of the mass units in the lens (electrons and protons) must be of the order of ΔX and hence most of X must be a vacuum. Then, if light passes through the lens, it must be travelling in a vacuum and its change of path at the boundary, and its change of motion in the lens (index of refraction) must be due to a change in the local fields in air and glass. Holding this view, the eclipse evidence did not astonish me at all. The gravitational field of the earth surely must be the summation of all the local fields, and these fields can be expected to differ among themselves. This is the local picture of refraction which has satisfied me for forty years.

In social life there is a similar phenomenon. What corresponds to local fields is the environment and training each of us receives, and this environment determines our personal standard of ethical and economic values. We use this standard and never doubt that it is a true (straight) standard, whereas many, many times, events prove our standards to be very badly warped. Our standard constitutes our premise from which reason must start. It is our *intuitions* based upon actual experience lived, not our reason, that determines our premise or standard. This is what the French philosopher Henri Bergson means when he writes about the limitations of the intellect or reason. Every mathematician knows very well that the geometry he builds up is tied to his postulates, and what Bergson means is that in social life postulates are determined by our personal unique past history, not by reason, just as "straightness" is determined by local force fields.

The economic evils which come from great differences in the distribution of wealth will be found to flow inevitably from the fact that the environment of the rich tends to warp

their standards completely out of shape relative to the standards of the poorer masses whose labor, of course, makes riches possible. In fact, any great amount of power concentrated in the hands of the few, tends to warp the standards of those few. That seems to be the teaching of all history. Reason has nothing to do with this and can not alter it any more than reason can alter the path of least effort on a gravitational field. We continually exaggerate the power of reason to eliminate friction. Troubles are inevitable whenever there is the simultaneous existence of mutually incompatible standards, accepted and used subconsciously by different people, each one assuming that HIS standard is right, or true, or straight in the Euclidean sense. It is because people in control of affairs get completely out of touch with the standard of living of the masses, that we have exploitation, social friction and wars. I think Abraham Lincoln understood this truth, perhaps better than any other great man of modern times.

We have had a small edition of this trouble in science recently. If we think of relativity as implying that the universe *in itself* is warped (and not warped and differently warped as measured on different systems) we may start a psychological war of the first magnitude; but if we realize that the warp is not in the universe itself; the warp is in our local standard of "straightness" with which we draw our local *pictures* (geometries) of the universe, then all mental confusion will disappear. Bergson once wrote "Many problems appear to be mysteries, simply because they are not stated correctly."

Plymouth Butane-Electric Locomotive.—(*Railway Age*, Vol. 99, No. 25.) Recognizing the advantages of replacing a steam locomotive with an internal combustion locomotive for switching, the Riverdale, Ill., plant of the Acme Steel Co. purchased from the Plymouth Locomotive Works a 65-ton double-unit, electric-drive locomotive, powered by two butane-burning engines. Among the favorable factors considered for this type engine was that the company stores on its property a large quantity of butane gas for other plant purposes and only the addition of a pump and fuel line to serve the locomotive was necessary. The locomotive is 40 ft. long over-all inside of the coupler knuckles, 14 ft. high over the cab and 10 ft. wide. It is equipped with two Climax 8 cylinder 6 in. by 7 in. heavy duty gasoline engines modified in point of compression ratio and carburetion equipment to burn butane fuel and designed to produce 523 hp. at 1200 r.p.m. Each of these engines is directly connected through heavy thermoid couplings to a General Electric Type GT-1160A d.c. generator, with a continuous rating of 290 amps. at a nominal voltage of 500, which supplies current to the truck motors over which each is mounted. Each of the truck motors develops 116 hp. for 1 hour at a nominal voltage of 250. Two butane tanks, of 125 gal. capacity each, are suspended beneath the locomotive frame and are interconnected to equalize the pressure and fuel level. At approximately 10 deg. F. and above, the vapor pressure of the fuel forces the gas into the mixing valves mounted in place of the carburetors on the main engines. It is reported that the locomotive has been consuming an average of 10.75 gal. of fuel and 0.1 gal. of lubricating oil per hour in heavy plant switching.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

MEETING OF FEDERAL FIRE COUNCIL.

On January 31 Dr. Lyman J. Briggs, Director of the National Bureau of Standards presided over a meeting of the Federal Fire Council in the Commerce Building, at which 30 representatives from Government departments and establishments were present.

A report was presented on surveys of the buildings of the National Agricultural Research Center at Beltsville, Maryland. Ten groups of important buildings and numerous smaller structures are scattered over a tract of 5,000 acres. Some of these house valuable plants and stock, developed as the result of painstaking research. Their loss, if not irreparable, would set back the work by many years.

Recommendations were made for reducing hazards from heating and refrigeration, for increasing the water supply for fire fighting, and for the installation of hydrants, standpipe and hose, manual and automatic fire alarm equipments and automatic sprinklers. Provisions for a fire engine and the organization of a fire company were also given consideration.

Another report dealt with the establishment of fire resistance standards for the design of Federal buildings by the Office of the Supervising Architect. During the past year such standards were set up for buildings of the Post Office or combined Post Office, Court House, and general office accommodation types, in cost classifications up to $500,000. The plans of the new building for the Department of the Interior have also been reviewed.

Another group (which reports to the Treasury Department and has been assisted in its work by members of the Federal Fire Council) gave an account of surveys and of improvements already made or planned for the Treasury Building, the Treasury Annex Building, and the Wilkins Building. The Coast Guard occupies the last-named structure.

* Communicated by the Director.

The Council decided to undertake in the near future an inquiry into the general fire hazard conditions in the new Government buildings in Washington. Points to be considered are: Occupancies and equipment, control exercised in the allotment of space, provisions for periodic inspections, fire protection equipment (whether manual or automatic), and methods of fire extinguishment that will result in the least damage to building trim, decorations, and contents.

K_2O-PbO-SiO_2 GLAZES AND GLASSES.

Compositions containing only potassium oxide, lead oxide and silica were studied as glasses during the course of the determination of phase equilibria in the system of these oxides (Technical News Bulletin 224, December 1935).

Glasses in that portion of the ternary diagram lying on the silica side of the tie lines connecting the compound compositions $K_2O.4SiO_2$, $K_2O.PbO.4SiO_2$, $K_2O.4PbO.8SiO_2$ and $PbO.SiO_2$ are stable in air. Compositions in this area and near these tie lines fuse to a homogeneous glass with sufficient ease to be of possible commercial application. However, temperatures required to produce a glass, and the viscosity of the product, rise very rapidly with increase in silica. It is believed that the band or area of commercially usable compositions would be narrow. Compositions on the K_2O side of the tie lines mentioned are either unstable in air or, in that area bounded by the tie lines from $PbO.SiO_2$ and from PbO to $K_2O.2PbO.2SiO_2$, prone to devitrification. Also, nearly all compositions below a line connecting PbO with the $K_2O.PbO$ composition separate into two immiscible liquids.

The usefulness or lack of usefulness of a composition as a glass will generally determine also its potential value as a glaze for porcelain or earthenware. In addition, a glaze must have the proper thermal dilatation to "fit" the ware upon which it forms a coating. Unfortunately, the glasses examined, and which otherwise held promise of usefulness as glazes, all undergo volume changes on heating or cooling which are so high as to preclude their use on clay ware as now manufactured (with the exception of certain "high silica" "high talc" wall tile). Typical values will be found in the following

table, in which compositions are given in weight per cent., and expansion in microns per centimeter from room temperature to 300° C.

K_2O Per Cent	PbO Per Cent.	SiO_2 Per Cent.	Expansion Microns.	K_2O Per Cent.	PbO Per Cent.	SiO_2 Per Cent.	Expansion Microns.
—	78.8	21.2	27	8.9	43.5	47.6	24
—	69.0	31.0	25	11.7	28.1	60.2	23
6.4	60.8	37.8	28	16.9	40.0	43.1	36

BOILER FURNACE SLAGS.

The ordinary boiler furnace slags show, on petrographic examination, various minerals in a matrix of glass. These minerals are usually mullite, anorthite, corundum, some form of silica, and iron minerals. The amounts and kinds of minerals present and the fusing temperatures depend upon the composition of the slag in question. In order to obtain a clearer idea of the mineralization likely to take place, as well as the fusing temperatures, a study is being made of the CaO-Al_2O_3-SiO_2-Fe_2O_3 system in the areas common to typical boiler furnace slags. The temperatures, boundary lines, and compounds of the system CaO-Al_2O_3-SiO_2 being known, this system is used as the base of the tetrahedron whose apices are CaO, Al_2O_3, SiO_2 and Fe_2O_3. One portion of the level or plane obtained by adding 10 per cent. Fe_2O_3 has been studied. The area centers about the join of the silica-mullite, silica-anorthite, and anorthite-mullite boundary lines. The join of the mullite-corundum boundary line with the mullite-anorthite and anorthite-corundum lines is included. In general, the boundary lines of the 10 per cent. iron level follow the general direction of similar lines on the base, with a slight amount of shifting. In the area studied, iron minerals do not appear as the primary phase. The 10 per cent of Fe_2O_3, however, does cause a general lowering of temperature of from 100 to 200° C., at which the primary phases appear.

Several boiler furnace slags, whose history as to corrosion in service is known, and which contain approximately 10 per cent. iron, have been plotted on the diagram by assuming all fluxes present as lime. However, in spite of the fact that

fluxes other than lime are present in varying amounts, the correlation between corrosive action as shown in service, and what might be expected from the place on the diagram, is generally fairly good. The slags near the lines and the join showing the lowest temperatures, are the most corrosive as compared to those lying in the areas of higher temperatures. The slags lying in the anorthite area are all relatively corrosive, while those lying in the mullite area may or may not be, depending on nearness to the anorthite-mullite boundary line, and particularly near the join with the silica-mullite, and silica-anorthite lines. Where the slag lies away from these areas, and especially if near the corundum area the corrosion becomes less. Since a great many slags contain higher percentages of iron, future work will include mixtures containing 20 per cent. and 30 per cent. iron oxide.

COLORS AND FINISHES FOR CAST STONE.

The Bureau has just issued a pamphlet "Colors and Finishes for Cast Stone," Commercial Standard CS53-35. This aims to assist the writers of architectural specifications and designers of buildings by listing a series of standard samples of cast stone covering the more commonly selected finishes and colors available in that material. These particular colors and textures were selected by a committee of architects, and include rubbed, brushed, etched, and bush-hammered finishes and buff and gray colors. These master samples are on file at the Bureau as standards of reference. They have been duplicated by The Cast Stone Institute for distribution to architects, manufacturers, and others concerned with the production and use of cast stone.

It is not, however, the purpose of this standard to limit the range of colors, textures, and finishes in cast stone. Under its present scope it merely sets up tangible examples of the most frequently occurring colors and finishes. These samples provide standards of comparison by which cast stone of these particular colors and finishes can be specified and judged. To the extent that they exemplify cast stone of enduring and pleasing appearance these samples provide a standard of comparison for all cast stone regardless of color and finish.

The pamphlet includes a brief history of the project, a list of the official acceptors, and the membership of the standing committee. The standard became effective August 30, 1935. Copies are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

SUGARING OF MARBLE.

A peculiar effect of weathering on marble buildings and monuments, which destroys the coherence of the calcite or dolomite crystals, is commonly called "sugaring." This process is usually manifested by a very shallow layer of loosened crystals on the exposed surface. However, some cases have been noted where "sugaring" had occurred to a depth of an inch or more.

This kind of weathering has been the subject of a study at the Bureau for some time, but until recently attempts to reproduce a similar effect in the laboratory were not successful. Marble has a high resistance to frost action but a low resistance to acids. Strong acids readily dissolve the material without destroying the coherence of the crystals. A commonly accepted theory for "sugaring" of marble is that acid rain water penetrates the pores of marble before the acid is neutralized and, by dissolving the binding material, causes the crystals to fall apart.

Anhydride gases existing in the air are absorbed by rain water and converted into acids. Probably the most effective of these are sulphur dioxide and carbon dioxide. Since both of these gases are readily dissolved by water it seems evident that a hard rainfall would almost completely remove these gases from the atmosphere within a few seconds, and subsequent rainfall would not be appreciably acidified. Marbles absorb water very slowly and hence it seems likely that the acidified portion of the rainfall is washed off before an appreciable amount of absorption could occur.

Specimens of limestone and marble exposed to the weather showed measurable weight losses within a month and quite appreciable losses within a year. The specimens also showed decreases in bulk density which indicated that the amount of pore space had increased. In an effort to determine the

mechanism of this type of weathering it was assumed that the anhydride gases penetrated the pores of stone during dry weather and were converted to acids therein during rains. An experiment was devised to accelerate the action over that which would occur under actual conditions. Specimens were dried, then placed in a closed vessel and the air drawn out. Sulphur dioxide was then admitted to the vessel and finally water was admitted. This cycle was repeated several times before the specimens showed appreciable change in appearance. After 25 cycles a specimen of dolomitic marble sugared to a depth of one inch. Calcite marbles and limestones proved to be more resistant but after 40 cycles most of the specimens began to show definite deterioration. These cracked without "sugaring," probably due to internal pressures arising from the accumulation of calcium sulphate within the pores.

The test seems to offer possibilities as a means of determining the relative resistance of different deposits of stone to this phase of weathering. It may also prove of use in determining the value of preservative treatments designed to overcome the effects of weathering.

TRANSVERSE TEST BARS OF CAST IRON.

The so-called "arbitration bar," which in testing is loaded transversely until failure occurs, is very widely used for specifying the properties of cast iron. The preparation of transverse test bars free from "burnt on" sand and other surface defects is important as such defects may seriously impair the transverse strength. A pitted or roughened surface, for instance, may cause early breaking of the bar by stress concentration due to the so-called "notch effect." A study of molding material and casting technique which will produce test bars free from such defects has been under way at the Bureau for some time.

A method of casting transverse test bars in green sand molds made of a mixture of 8 parts of an iron molding sand and 1 part of sea coal, the mold cavities being faced with a carbonaceous non-graphitic material, has been found to be very satisfactory. Test bars of various diameters cast by

four different methods have been employed in testing several types of cast irons which had been heated to several maximum heating temperatures, the metal being poured approximately 300° F. above the liquidus temperature. Test bars vertically cast and bottom poured were most uniform in dimensions and hence gave most consistent results. The transverse strength was found to increase with increase of the maximum heating temperature. The results will form the basis of a technical report.

CARBONYL IRON.

Iron of a very high degree of purity, made by a process in which iron carbonyl is decomposed to give metallic iron and a gaseous constituent, has been enthusiastically received as a material on which the fundamental characteristics of this element can be determined. However, spectroscopic and analytical evidence obtained at this Bureau have indicated that carbonyl iron is not always so free from impurities as it has been claimed to be, and recently, determinations of the temperature coefficient of resistivity of carbonyl iron wire have given results which are not so reproducible as similar determinations on some other types of high purity iron. This result, it is believed, can be interpreted to mean that the structure is not always uniform, and that the impurities in carbonyl iron, minute in amount as they may be, are inclined to be segregated.

SUN LAMPS; THE CARBON ARC VERSUS SUNLIGHT.

In letter circular LC-225 of March 5, 1927, which summarized "Some Outstanding Accomplishments of the Bureau of Standards in 1926," there is included a short account of a research on the radiation emitted by the carbon arc lamp BS Sci. Pap. *21*, 535 (1926–27), in which it is stated that of all the artificial illuminants tested, the carbon arc is the nearest approach to sunlight in spectral energy distribution.

This statement of an observation that was already known in a general way is, of course, not an endorsement of any make of lamp by the National Bureau of Standards, yet this brief and incomplete item was seized upon for sales promotion of

carbon arc lamps. The Bureau, therefore, in Technical News Bulletin 140 (December, 1928) issued a supplementary statement on "The Carbon Arc Versus Sunlight" in which it is pointed out that while it is true that, of all the artificial sources available, the spectral radiation from the carbon arc is the closest approach to sunlight; even this source is far from being an exact match of sunlight, in spectral intensity. It contains ultraviolet radiation of very short wave-lengths and infrared rays of long wave-lengths which are not found in sunlight.

By covering the carbon arc with a screen of special glass it is possible to shut out the ultraviolet of short wave-lengths and the infrared rays of long wave-lengths. Nevertheless, there remains a selective emission band of ultraviolet radiation (the "cyanogen band") the intensity of which is far in excess of that observed in sunlight.

For some years sales promotion literature containing quotations from LC-225 has been in abeyance. Recently this incomplete statement from LC-225, with no reference to Technical News Bulletin 140, has been revived in advertisements of "Health lamps" and "Sun lamps," with the inevitable result that this Bureau receives repeated requests regarding the reliability of the claims made for such lamps,—including carbon arc and tungsten filament lamps.

The Bureau wishes, once more to call attention to the fact that without an elaborate combination of filters no artificial source of radiation has yet been devised and there is, consequently, no lamp on the market that has a spectral energy distribution identical with that of sunlight, moreover, in purchasing any lamp, its spectral energy distribution curve is not the only thing to be considered. Hazard from fire and from burns which may result from contact with the housing of the lamp, as well as the possibility of generating disagreeable odors should all be carefully investigated.

MAP SHOWING TIME ZONE BOUNDARIES.

The standard time boundaries for the United States with adjacent parts of Canada and Mexico, correct as of October 1, 1935, are shown on a map released last month by the Bureau.

This map, Miscellaneous Publication M155, is a revision of one published in 1930 which has been in wide demand by schools, colleges, radio broadcasting stations, transportation agencies, hotels, manufacturers, and the general public. Educational institutions will find this publication useful as a companion to Circular C406, Standard Time Throughout the World, issued last year.

The base map was supplied by the U. S. Geological Survey, and the time zone boundary lines were placed upon it as the result of information furnished by the Interstate Commerce Commission, the Hydrographic Office of the Navy Department, and the Dominion Observatory of Canada. The boundaries were drawn by R. E. Gould, chief of the Bureau's time section, and were checked by the Interstate Commerce Commission.

The map is printed in light blue on a white background. State boundaries and names, and the names of cities are in black. Time zone boundary lines appear in red and each time zone is provided with a clock dial showing at a glance the difference in time between any two zones. The letters designating the zones and longitude west from Greenwich are in large red block letters.

The dimensions of the map are 20 × 30 inches, and the paper, while light, is of good quality. Copies of the map are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

Studying Parts in Motion with the New Stroboglow.—R. C. HITCHCOCK. (*Electric Journal*, Vol. 32, No. 12.) Visual analysis of moving machinery is often necessary to bring to light phenomena which occur only at the time of movement and are not apparent at rest. For this purpose an instrument known as a stroboscope is used which enables one, for instance, to visualize a moving part as if it were stationary, speeded up or slowed down. A cracked spoke in a wheel might never be detected by ordinary inspection, but by using stroboscopic light—light of short duration timed once per revolution—the failure becomes clearly visible at working speed. Among the desirable features for a stroboscope are (1) high intensity of light over a reasonably wide angle, (2) short duration of flash, (3) frequency of timing adjustable at lamp unit, (4) flashing speed either internal or timed from machine being viewed, and (5) calibration possible without external equipment. To meet these requirements a new Stroboglow has been designed. It consists of three units, the power, the lamp, and the contactor. The power unit is essentially a transformer supplying the necessary voltages to the lamp circuit. The lamp unit houses the stroboscopic lamp and an electronic timer for producing the flashes of the lamp at the desired rate. The contactor is an auxiliary piece of apparatus and is used only when it is desired to have the machine being viewed control the flashes of the lamp. Timing of the Stroboglow can be made by using the contactor, externally as from an automobile ignition system, and by means of the electronic timer. The latter consists of an amplifier tube whose grid circuits are controlled by potentiometers and a range knob. This tube periodically charges a condenser, which, when it reaches the proper potential, causes the grid of a gas-filled timing tube to permit a discharge to pass through its plate circuit. This circuit includes the primary of a special spark coil. The lamp is continuously supplied with filtered direct current that is sufficient to cause a flash only when the spark coil is energized.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, MARCH 18, 1936.

The regular monthly meeting of the Institute was called to order at 8:30 o'clock by Mr. Walton Forstall, Vice-president. He announced that the minutes of the previous meeting had been printed in the March issue of the JOURNAL of the Institute, and if there were no objections or corrections, the minutes would be approved. Upon hearing none, the chairman declared them approved as read.

The Secretary then reported the following additions to membership: Institute members—23, Museum members—101, total—124.

The Secretary also called attention to a series of demonstrations and lectures on Science in Crime Detection which were now going on daily in the lecture hall. Finger-printing, forensic ballistics, handwriting, blood tests, are among the subjects which will be considered during the next several weeks. The course will continue until mid-summer.

The chairman then introduced Mr. Nevin E. Funk, Vice-president, Philadelphia Electric Company, who presented a paper on "The Fundamental Factors Controlling the Choice of Steam Electric Generating Station Sites." The speaker discussed the general requirements for generating station sites, the transmission of power, accessibility of water and fuel supply and the factors determining plant size. By means of lantern slides he presented data on installation costs, comparison of efficiency of old and new plants, and the operating and investment cost per year. Factors determining choice of locating the plant at a distant coal mine or at a load center were also pointed out.

A brief discussion followed the paper, in which Messrs. Dodge, Porter, Fernald and others took part. The chairman extended the thanks of the meeting to the speaker. Adjourned,

HENRY B. ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 11, 1936.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 11, 1936.

MR. JOHN A. VOGLESON *in the Chair.*

The following reports were presented for final action:

No. 3012: Clark Medal.

This report recommended the award of the Walton Clark Medal to Dr. Joseph Becker, of Pittsburgh, Pennsylvania, "In consideration of his improvements in the art of the carbonization of coal and manufacture of gas in coke ovens, and particularly for his work in the development of the oven known as the 'Becker Oven.'"

No. 3013: Literature.

This report recommended the award of the Louis Edward Levy Medal to Mr. Mayo Dyer Hersey, of Brown University, Providence, Rhode Island, for his series of papers on "A Short Account of the Theory of Lubrication," published in the June, July, August, and September issues of the JOURNAL of the Institute for 1935.

The following report was presented for first reading:

No. 3003: Work of Dr. G. O. Curme, Jr.

GEO. A. HOADLEY,
Secretary to the Committee.

LIBRARY NOTES.

RECENT ADDITIONS.

American Foundrymen's Association. Transactions 1934. Volume 42. 1935.

American Society of Heating and Ventilating Engineers. Guide. Volume 14. 1936.

ARKIN, HERBERT, AND RAYMOND R. COLTON. Graphs: How to Make and Use Them. 1936.

BABLIK, HEINZ. Galvanizing. A Theoretical and Practical Treatise for the Use of Works Managers, Students and Others. Translated by Margaret Juers. Budicky. Second Edition. 1936.

Beilstein's Handbuch der organischen Chemie. Vierte Auflage. Erstes Ergänzungswerk. Bd. 20–22. 1935.

BORN, MAX. The Restless Universe. Authorized Translation by Winifred M. Deans. 1936.

DAVIES, W. L. The Chemistry of Milk. 1936. Being Volume Ten of a Series of Monographs on Applied Chemistry.

FARADAY, MICHAEL. Faraday's Diary. Volume VII and Index. 1936.

GILL, AUGUSTUS H. Power Plant Chemistry. Formerly Published under the Title of Engine Room Chemistry. Fourth Edition, Revised and Enlarged. 1935.

GLASSTONE, S., AND A. HICKLING. Electrolytic Oxidation and Reduction: Inorganic and Organic. 1935. Being Volume Nine of a Series of Monographs on Applied Chemistry.

HARRIS, LESLIE J. Vitamins in Theory and Practice. 1935.

HUND, AUGUST. Phenomena in High Frequency Systems. First Edition. 1936. International Series in Physics.

Kaiser Wilhelm-Gesellschaft zur Förderung der Wissenschaften. 25 Jahre. Herausgegeben vom Präsidenten Max Planck. Erster Band: Handbuch; Zweiter Band: Die Naturwissenschaften. 1936.

KITTREDGE, GEORGE W., AND ASSOCIATES. The New Metal Worker Pattern Book. Revised and Enlarged Edition Including Some New Problems by Frank X. Morio. 1935.

National Fire Protection Association. Crosby-Fiske-Forster Handbook of Fire Protection. Eighth Edition 1935. Robert S. Moulton, General Editor. 1936.

NELSON, W. L. Petroleum Refinery Engineering. First Edition. 1936.

Office International de Chimie. Répertoire International des Centres de Documentation Chimique. 1935.

Pharmacopœia of the United States of America. Eleventh Decennial Revision. Official from June 1, 1936.

Scientific American Publishing Company. Amateur Telescope Making. Albert G. Ingalls, Editor. Fourth Edition. 1935.

SEIFRIZ, WILLIAM. Protoplasm. First Edition. 1936.

SNELL, FOSTER DEE, AND CORNELIA T. SNELL. Calorimetric Methods of Analysis Including Some Turbidometric and Nephelometric Methods. Volume 1: Inorganic. 1936.

TSCHIRCH, A., AND ERICH STOCK. Die Harze. Dritte umgearbeitete Auflage. 2 Band, 2 Hälfte, 1 Teil. 1935.

VAN WERT, LELAND RUSSELL. An Introduction to Physical Metallurgy. First Edition. 1936.

Who's Who in Commerce and Industry. 1936.

WRIGHT, L. K. Official Refrigeration Manual. Volume 2. 1935.

YOUNG, VINCENT W., AND GILBERT A. YOUNG. Elementary Engineering Thermodynamics. First Edition. 1936.

BOOK REVIEWS.

LIFE AND EXPERIENCES OF A BENGALI CHEMIST, by Prafulla Chandra Rây. Vol. II, 469 pages, 15 × 22 cm. Chuckervertty, Chatterjee & Co., Ltd., Calcutta; Kegan Paul, Trench, Trubner & Co., Ltd., London, 1935. 6 shillings.

Volume I of P. C. Rây's memoirs was reviewed in this JOURNAL, **219**, 392 (1935). In Volume II the author presents much valuable material left out of Volume I.

Few chemists in history have been so intimately in contact with the educational, scientific, economic, sociological, political and historical development of their countries. From the vantage point of a long and active life Rây is able to render considered opinions on a multitude of subjects of complexity and importance. But his background is by no means confined to the events of his lifetime as his study of the development of education in India from the time of the first British ruler in India so completely demonstrates.

The section on socio-economic problems deals with subjects as diverse as the mentality and psychology of the youth of Bengal, the Youth Movement and mass education in China, culture and money making, malaria and the railways, and tuberculosis in Bengal, with a whole chapter devoted to floods and the influence of improperly engineered railway and canal construction thereon, with consequent effects on drainage, sanitation and health.

In the section on politico-economic problems comprising one-fifth of the volume, the author is particularly bitter relative to the effects of British rule. Much of this will be read with sympathy and understanding in many another nation, and it is this side of the picture which has but rarely been opened to the world. Among the subjects considered are the military organization and its consequent burdens in India, the consequence of the restriction of opportunity for advancement to the native population either in military or political life, govern-

mental extravagance, public debt and British imperialism. In the author's preface we read: "It is sad to reflect that there has been no material change of policy of the British government during the last fifty years; any change that has occurred is only a *change for the worse* as evidenced by the New Constitution. The problems—social and economic—which were acute then have become acuter still."

Miscellaneous chapters discuss subjects as unrelated as law and its administration, expensive habits of university students, drain of the wealth of the land due to European standards of living, scientific specialization and narrow outlook, old age and how to battle against it, the rôle of accident in science, national industries, contrasts between oriental and occidental viewpoints on business and many other subjects of interest by no means limited to India.

Few men of such diverse accomplishments and broad interests have succeeded in presenting their mature philosophy to the world at large. The completion of Volume II of these experiences must be a source of immense personal gratification, the culmination of a worthy life.

LESLIE R. BACON.

INTERNATIONAL HANDBOOK OF THE BY-PRODUCT COKE INDUSTRY, by Prof. Dr. W. Gluud. American Edition, by D. L. Jacobson. 879 pages, plates, illustrations, tables, 16.5 × 24 cms. New York, The Chemical Catalog Company, Inc., 1932. Price $15.00.

The industry with which this book deals has assumed tremendous proportions in America and abroad and the need for compact information useful to this industry has been acute. Much of this information has been available only in scattered form and therefore the publication of this book should answer a long felt need. F. W. Sperr, Jr., in the preface to this edition points out that—

"To the American reader, the outstanding value of this book will be its wealth of particulars relative to European theory, invention, and experience which has hitherto been generally inaccessible here. Much of the descriptive material concerning American practice has never previously appeared in book form anywhere. In presenting this material, the primary objective has been to draw a complete picture of the international by-product coke industry. No attempt has been made to include information of a subordinate nature fully familiar or readily available in this country."

There are three divisions to the book. The first, called the "Scientific Section," begins with the origin of coal and proceeds through chemical composition and classification. A chapter is devoted to coal deposits with particular reference to coking coals in Europe, Asia, America, Africa and Australia. Analysis, swelling and coking properties, weathering, spontaneous combustion and destructive distillation of coal are all given careful attention. An appendix to this section gives statistics in world coke production.

The second division of the book entitled "Technical Section" covers the greater portion of the book, some 679 pages. Here is a remarkable exposition of the industry. From the selection of coal and preparation of it for coking, the reader is taken through the process in the coke oven, the development of the oven and various types, and steam generation in American and European coke oven plants. The recovery of ammonia and benzol, and the composition and removal of hydrocyanic acid from coke oven gas are given due consideration as well as tar distillation at the plant. An appendix discusses briefly a new development in European coke ovens, the Koppers Recirculation (Kreisstrom) Combination Oven.

The third division consists of an index of authors and subjects, a very necessary and helpful division in a book of this type.

The book is first of all a reference work, adequate and complete, with a great many illustrations and drawings. Being a handbook, its data cover a vast field. In addition to this the method of presentation makes the book, in reality, more than a handbook, something of the nature of a treatise or even a text. Throughout, references are made and duly recorded to work of a large number of investigators and to patents on the various subjects. These, together with completeness of coverage, should make the book of tremendous value to this industry as well as allied industries.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 528, Reduction of Hinge Moments of Airplane Control Surfaces by Tabs, by Thomas A. Harris. 32 pages, illustrations, tables, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price 10 cents.

An investigation was conducted in the N. A. C. A. 7- by 10-foot wind tunnel of control surfaces equipped with tabs for reducing the control forces or trimming the aircraft. Two sizes of ordinary ailerons with several sizes of attached and inset tabs were tested on a Clark Y wing. Tabs were also tested in combination with auxiliary balances of the horn and paddle types, and with a Frise balanced aileron. A tail-surface model of symmetrical section, equipped with tabs, was tested with 40 per cent. of the area movable (elevator) when used as a horizontal tail and 60 per cent. of the area movable (rudder) when used as a vertical tail. The half-span tail-surface model was tested with and without a reflection plane.

Complete detailed results of the tests are tabulated in standard nondimensionsal coefficient form. The aileron test data are discussed for one aileron movement and graphs of control force against rolling-moment coefficient are included. Curves showing the effect of the tabs as trimming or as servo-control devices are given. For the tail surfaces, the effectiveness of tabs in reducing the control force and in trimming and servo operation is discussed and figures are included.

The effect of angular velocities on the application of the data to complete airplanes is considered and also the effect of the difference in the wind-tunnel test set-up from the actual arrangement on an airplane.

The results of the tests indicated that inset tabs were superior to attached tabs for the same ratio of tab/control-surface deflection. The greatest reduction in control force occurred at 0° angle of attack. The tabs could be used satisfactorily as trimming devices and also to reduce the control force for control moments as large as those ordinarily obtained by deflecting the control surface 15° or less. The reduction of hinge moments due to tabs could be added directly to the reduction due to paddle, horn, or Frise types of balance. Angles of yaw up to 20° had no appreciable effect on the reduction of hinge moments due to tabs.

Report No. 530, Characteristics of the N. A. C. A. 23012 Airfoil from Tests in the Full-Scale and Variable-Density Tunnels, by Eastman N. Jacobs and William C. Clay, 10 pages, illustrations, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price five cents.

This report gives the results of tests in the N. A. C. A. full-scale and variable-density tunnels of a new wing section, the N. A. C. A. 23012, which is one of the

more promising of an extended series of related airfoils recently developed. The tests were made at several values of the Reynolds Number between 1,000,000 and 8,000,000.

The new airfoil develops a reasonably high maximum lift and a low profile drag, which results in an unusually high value of the speed-range index. In addition, the pitching-moment coefficient is very small. The superiority of the new section over well-known and commonly used sections of small camber and moderate thickness is indicated by making a direct comparison with variable-density tests of the N. A. C. A. 2212, the well-known N. A. C. A. family airfoil that most nearly resembles it. The superiority is further indicated by comparing the characteristics with those obtained from full-scale-tunnel tests of the Clark Y airfoil.

A comparison is made between the results for the newly developed airfoil from tests in the N. A. C. A. variable-density and full-scale wind tunnels. When the results from the two tests are interpreted on the basis of an "effective Reynolds Number" to allow for the effects of turbulence, reasonably satisfactory agreement is obtained.

Report No. 534, Aerodynamic Characteristics of a Wing with Fowler Flaps including Flap Loads, Downwash, and Calculated Effect on Take-Off, by Robert C. Platt. 17 pages, illustrations, tables, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price 10 cents.

This report presents the results of an investigation in the N. A. C. A. 7- by 10-foot wind tunnel on a wing in combination with each of three sizes of Fowler flap. The purpose of the investigation was to determine the aerodynamic characteristics as affected by flap chord and position, the air loads on the flaps, and the effect of the flaps on the downwash. The flap position for maximum lift; polars for arrangements considered favorable for take-off; and complete lift, drag, and pitching-moment characteristics for selected optimum arrangements were determined. A Clark Y wing model was tested with 20 per cent. c, 30 per cent. c, and 40 per cent. c Fowler flaps of Clark Y section. Certain additional data from earlier tests on a similar model equipped with the 40 per cent. c Clark Y flap are included for comparison. Results of calculations made to find the effect of the Fowler flap on take-off, based on data from these tests, are included in an appendix.

The maximum lift coefficient obtainable, based on original wing area, had a nearly linear increase with flap chord up to 40 per cent., but the maximum lift force per unit of total area increased very little beyond the value obtained with the 30 per cent. c flap. The maximum load on the flap occurred very nearly at the maximum lift of the wing-flap combination and was nearly 1½ times the load that would result from uniform distribution of the total load over the total area. In general, the flap appeared to carry a large proportion of the additional lift caused by its presence and to have its center of pressure much nearer the leading edge than it would normally be in free air. The addition of the Fowler flap to a wing appeared to have no appreciable effect on the relation between lift coefficient and angle of downwash. The calculations in the appendix show that, by proper use of the Fowler flap, the take-off of an airplane having wing and power loadings in the range normally encountered in transport airplanes should be considerably improved.

Report No. 543, Tank Tests of N. A. C. A. Model 40 Series of Hulls for Small Flying Boats and Amphibians, by John B. Parkinson and John R. Dawson, 29 pages, illustrations, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price fifteen cents.

The N. A. C. A. model 40 series of flying-boat hull models consists of two forebodies and three afterbodies combined to provide several forms suitable for use in small marine aircraft. One forebody is of the usual form with hollow bow sections and the other has a bottom surface that is completely developable from bow to step. The afterbodies include a short pointed afterbody with an extension for the tail surfaces, a long afterbody similar to that of a seaplane float but long enough to carry the tail surfaces, and a third obtained by fitting a second step in the latter afterbody.

The various combinations were tested in the N. A. C. A. tank by the general method over a suitable range of loadings. Fixed-trim tests were made for all speeds likely to be used and free-to-trim tests were made at low speeds to slightly beyond the hump speed. The characteristics of the hulls at best trim angles have been deduced from the data of the tests at fixed trim angles and are given in the form of nondimensional coefficients applicable to any size of hull.

Comparisons among the forms are shown by suitable cross plots of the nondimensional data and by photographs of the spray patterns. The difference between the results obtained with the two forebodies was small for the smooth-water conditions simulated in the tank. With the same forebody in each case, the resistance of the no-step afterbody was least at the hump speed and that of the pointed afterbody was least at high speeds.

Take-off examples of an 8,000-pound flying boat or amphibian having a power loading of 13.3 pounds per horsepower and a 2,000-pound flying boat having a power loading of 18.2 pounds per horsepower are included to illustrate the application of the data.

Report No. 544, Combustion in a Bomb with a Fuel-Injection System, by Mildred Cohn and Robert C. Spencer, 12 pages, illustrations, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

Fuel injected into a spherical bomb filled with air at a desired density and temperature could be ignited with a spark a few thousandths of a second after injection, an interval comparable with the ignition lag in fuel-injection engines. The effect of several variables on the extent and rate of combustion was investigated: Time intervals between injection and ignition of fuel of 0.003 to 0.06 second and one of 5 minutes; initial air temperatures of 100° C. to 250° C.; initial air densities equivalent to 5, 10, and 15 absolute atmospheres pressure at 100° C.; and air-fuel ratios of 5 to 25.

The 5-minute interval between injection and spark permitted the fuel to vaporize completely; for the shorter periods the explosion took place with liquid-vapor mixtures. For the short periods, the time of reaction increased as the period was increased and the response of combustion to changes in the initial conditions was more marked than it was for the long period, indicating the significance of distribution and vaporization. An increase in initial temperature decreased the time of reaction for both types but increased the extent of com-

bustion for only the short-period mixtures. For the uniform vapor-air explosions, an increase in air density lengthened the reaction time. For the nonuniform liquid-vapor-air explosions, an increase in air density from 0.00473 to 0.0095 gram per cubic centimeter (equivalent to 5 and 10 atmospheres pressure at 100° C.) shortened the time of reaction but (with the exception of the tests at 100° C.), as the density was increased to 0.0142 gram per cubic centimeter (equivalent to 15 atmospheres pressure at 100° C.), the reaction time tended to lengthen. The leanest mixture that would explode with a delay period of 5 minutes corresponded to an air-fuel ratio of 20.7. For a delay period of 0.004 second it corresponded to one of 25. The reaction time was a minimum and the maximum pressure a maximum at an air-fuel ratio of 10 for the delayed explosions. At the higher densities and temperatures, the two types of explosions acted more alike.

Report No. 545, Effects of Air-Fuel Ratio on Fuel Spray and Flame Formation in a Compression-Ignition Engine, by A. M. Rothrock and C. D. Waldron. 9 pages, illustrations, 20 × 26.5 cms. Washington, Superintendent of Documents, 1935. Price 5 cents.

High-speed motion pictures were taken at the rate of 2,500 frames per second of the fuel spray and flame formation in the combustion chamber of the N. A. C. A. combustion apparatus. The compression ratio was 13.2 and the speed 1,500 revolutions per minute. An optical indicator was used to record the time-pressure relationship in the combustion chamber. The air-fuel ratio was varied from 10.4 to 365. The results showed that as the air-fuel ratio was increased definite stratification of the charge occurred in the combustion chamber even though moderate air flow existed. The results also showed the rate of vapor diffusion to be relatively slow.

Report No. 546, The Effect of Turbulence on The Drag of Flat Plates, by G. B. Schubauer and H. L. Dryden. 7 pages, illustrations, 23.5 × 29 cms. Washington, Superintendent of Documents, 1935. Price 5 cents.

In determining the effect of turbulence on the forces exerted on bodies in the air stream of a wind tunnel, it is commonly assumed that the indications of the standard pitot-static tube used to determine the air speed are not dependent on the turbulence. To investigate the truth of this assumption, the drag of a normally exposed flat plate, the difference in pressure between the front and rear of a thin circular disk, the rate of rotation of a vane anemometer, and the pressure developed by a standard pitot-static tube were measured in an air stream for several conditions of turbulence. The results may be interpreted as indicating that there is no appreciable effect of turbulence on the vane anemometer and the standard pitot-static tube, but that there is a small effect on the drag of a flat plate and the pressure difference between front and rear of a disk. This drag was found to be independent of the speed or Reynolds Number and hence the observed turbulence effect is of a different nature from the effects observed on skin-friction plates and airship hulls or on spheres.

This work was conducted by the National Bureau of Standards with the coöperation and financial assistance of the National Advisory Committee for Aeronautics.

Report No. 548, Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics, by Joseph A. Shortal. 10 pages, illustrations, tables, 20 × 26.5 cms. Washington, Superintendent of Documents, 1935. Price 5 cents.

Tests were conducted in the N. A. C. A. 7- by 10-foot wind tunnel to determine the effect of wing-tip shape and dihedral on some of the aerodynamic characteristics of Clark Y wings that affect the performance and lateral stability of airplanes. Force tests at several angles of yaw and rotation tests at zero yaw were made. From these tests the rates of change of rolling-moment, yawing-moment, and cross-wind force coefficients with angle of yaw and the rate of change of rolling-moment coefficient with rolling were determined.

The tests showed that the plan form of a wing tip as well as the elevation shape had considerable effect on the rate of change of rolling- and yawing-moment coefficients with angle of yaw. The tests also showed that with dihedral of only the outer one-fourth of each semispan, the dihedral effect was maintained to a much higher angle of attack than when the complete semispan had dihedral. At normal angles of attack, the increments of rate of change of rolling moment with angle of yaw due to dihedral may be calculated with satisfactory accuracy.

THE EARTH AMONG THE STARS. By Marian Lockwood and Arthur L. Draper. 91 pages with figures, 14 × 19 cm. Basic Books, Inc., New York. 1935. Price 35 cents.

In eight brief chapters the authors present in inexpensive form authoritative information for the general reader. A good deal of imagination has gone into this little volume, not concerned with the facts at hand but with the method of address to the reader. The material should all be within the comprehension of average high school students. Photographs occupy full pages without margins and are quite satisfactory for their purpose. The drawings, however, are somewhat too fantastic to excite much enthusiasm in a realist.

There is an index covering a fair selection of material. Some idea of its scope may be gained by its inclusion of the big dipper but omission of the small dipper. No mention is made of the zenith, or of the zodiac but references are found to the spectroscope. Eclipses are missing but globular clusters of stars are in. Of course there is considerable discussion of eclipses in the text.

The reviewer likes to pick up a simple volume occasionally, dealing with a subject with which he has little or much familiarity. If little, he gathers a maximum of essential knowledge with a minimum effort and expenditure of time. If considerable, a quick perusal always serves to refresh his mind on fundamentals and their interrelations. Such brief volumes as this can serve doubly useful purposes therefore when prepared by writers competent both scientifically and pedagogically.

LESLIE R. BACON.

RADIO PHYSICS COURSE, by Alfred A. Ghirardi, E. E. 972 pages, illustrations, tables, 17 × 23 cms. New York, Radio & Technical Publishing Co., 1933. Price $4.00.

Here is a book that contains between its two covers a text of radio telegraphy and radio telephony reception in particular, television and even sound motion pictures for the student for practical applications. Written in a clear and simple

manner it tells the whys and wherefores of most anything an amateur experimenter, an amateur short wave enthusiast, or a serious minded student of the subject with a view of making this his vocation, may ask. It is a remarkable exposition of covering its field in as non-technical a way as possible and thereby creating increased interest from the start. While primarily intended as a text in radio schools, it can be used very nicely for home study.

The first third of the book is devoted to the fundamentals of electricity—direct and alternating currents and the electron theory. There has seldom, if ever, appeared a more clearer, compact and as interesting a treatment on these subjects for the purpose of preparing an elementary student for the subjects which follow. Because of the recent changes in views of the electron theory, it is interesting to note how the author treats this subject so as to leave the impression that the theory presented is the most plausible at present, leaving open the thought of possible changes to come. This part of the book gives adequate foundation for the next treatment on vacuum tubes, their characteristics and construction features.

Vacuum tube use in radio receivers is covered as detectors and amplifiers, which is followed by portions devoted to superheterodyne receivers and the design of radio frequency amplifiers and tuning coils. Various types of receivers are considered, including automobile and aircraft receivers as well as special chapters on phonograph pickups and sound amplifier systems, and short wave reception. The chapter on television gives the present status of this development and what to expect in the future, then proceeds to outline the transmission of pictures and the various apparatus and methods employed.

Supplementing the data on radio receivers, there is a very good treatment on testing and servicing receivers. Practical short-cut methods are described as well as instruments for circuit analysis. Here the reader is impressed with the viewpoint that trouble should be looked upon in a cool appraising manner as to the apparatus as a whole before proceeding in a specified way to its detection. Concluding the book, the explanation of how sound motion pictures are made and operate is quite interesting as well as instructive.

Appendixes contain much useful mathematical data and tables. The very comprehensive index at the end of the book makes it valuable as a reference work, in addition to its usefulness as a text, for use of all those whose interests lie in this direction whether students or workers. The many diagrams and illustrations add greatly to making the contents impressive.

R. H. OPPERMANN.

REPERTOIRE INTERNATIONAL DES CENTRES DE DOCUMENTATION CHIMIQUE (IN THREE LANGUAGES), 114 pages, 21.5 × 30 cms. Paris, Office International de Chimie, 1935.

This book is the beginning of an effort, on an international scale, to make available sources of chemical information to all enquirers on any chemical subject. Too much cannot be said in favor of an organized method of accomplishing this and according to the preface, work along these lines has been started by the International Union of Chemistry. This book is the result of the start—a listing of existing documentation centers, including those open to the public, to members of a Learned Society etc., to the exclusion of the documentation services set up by the several administrations, industrial or commercial firms, for their private needs.

The book covers many countries, U. S., France, Germany, Great Britain, etc. Information on the collection, subjects, staff and other information is recorded in the language of the country in which the library listed is located. In the United States, there are but seven libraries listed as centers of chemical documentation, a small number considering the vast amount of chemical research carried on here annually on a great many subjects requiring literature searches and bibliographies. As a matter of fact, many technical librarians can recall with little effort a number of libraries that should be listed here, located not only in the United States but in other countries as well. The preface, however, states that, "To be sure, the enquiries made by the Office have not brought to light all the existing centers of documentation. The putting into circulation of the first edition of the Repertory may be expected to reveal a certain number of others which it will be profitable to include in a subsequent edition.

"The 'International Repertory of Centers of Chemical Documentation' will be kept constantly up to date and the Office will gladly welcome all dedications enabling it to complete or to amend its files."

R. H. OPPERMANN.

PHOTO-ELECTRIC AND SELENIUM CELLS, THEIR OPERATION, CONSTRUCTION AND USES, by T. J. Fielding. 140 pages, illustrations, 12.3 × 19.5 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $1.75.

If you are a practical man or student with limited knowledge of the theory and use of light sensitive cells, desiring to become familiar with this subject, this book should prove valuable. While, in the very recent past, the variety of applications of such cells in industry has increased tremendously, the possibilities have only been touched upon, and the knowledge that may be derived from this readily understandable little book should prove inspiring to the inventively minded as well as being applicable to practical present operating installations. The book contains only 138 pages of approximately 12 point type well illustrated with photographs and diagrams.

In the beginning the reader is introduced to a treatment on the photo-electric effect which treatment necessarily contains brief references to the historic as well as to the essentials of the electron theory. Following this there is space given to the practical construction of selenium cells, amplification of the photoelectric current—valve and transformer—in order that the operation of relays is made possible, and the practical construction of the amplifier. The spectrum is next given treatment and there is described how cells can be constructed, using various photoelectric metals, so as to give different desired responses under various color applications. A chapter is devoted to home experiments with light sensitive cells wherein it is told how a simple test can be made of their sensitivity and various simple experiments and applications. The remaining half of the book is devoted to the great variety of applications of photo-cells—in television and talking pictures, in industry, the photo-electric gramophone, uses in advertising, ingenious applications, and finally a discussion of the potentialities of the light sensitive cell.

In the latter discussion it is pointed out the field of activities of such cells will continue to widen and their established position in industry will be further strengthened when the extent of the potentialities is more completely realized and understood by the designer, engineer and practical man. Herein lies the

justification and value of the book—to further understanding. As stated above the book is a practical presentation for the practical man. As such, briefness and clarity are paramount.

R. H. OPPERMANN.

PHENOMENA IN HIGH-FREQUENCY SYSTEMS, by August Hund, first edition. 642 pages, diagrams, tables, 15 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1936. Price $6.00.

The popularity of reference books to research workers who need information quickly, often rests on their mental set-up, conditions and situation of the user at the time of seeking information, and the training of the user. Books which are so constructed that trouble is experienced in obtaining assistance for whatever reason, are cast aside and others are selected. This applies to the handbook as well as the reference work on theories and formulæ.

The book at hand is of the latter type, a thorough, modern presentation of high frequency phenomena and phenomena within parts of apparatus and systems which are used in radio as well as in the communication field. A short perusal through it establishes that the construction and methods of approach are brief and concise for quick and ready reference as to the various theories and laws treated. It is divided into thirteen chapters, each covering a subject in its entirety. Phenomena and actions in tubes are discussed with respect to basic principles, without too much stress on tube design; phenomena in filament—as well as filament-less—tubes are dealt with in detail; piezo-electric phenomena correlating the pioneer work of Voigt with present day findings and applications is presented; ionic and electronic oscillations within tubes as well as in the ionized regions of the upper atmosphere are discussed in detail. A brief review of classical experience and theory precedes many of the discussions so that it should not be necessary to consult other texts in order to understand diffcult descriptions given in this book.

Treatment of special interest to many is found in Chapter XI, and it may serve as an illustration of the completeness of coverage found in the rest of the book. Here, in admirable fashion is given a description of lines of long and short electrical length with special reference to antenna problems. This, of course is entirely mathematical, but the skill of the author enables the student as well as the researcher to absorb the data and theories with reasonable concentration and ease. Similarity to the transmission line is relied upon basically and treatment is interesting on current and voltage distribution along lines and antennas and possible modes, and effective antenna reactance for the loaded and unloaded antenna.

The book is complete with all the necessary diagrams, curves and tables to facilitate understanding. An appendix of useful relations and tables precedes a very useful subject index of 30 pages.

R. H. OPPERMANN.

FOUNDATIONS OF PHYSICS, by Robert Bruce Lindsay, Ph.D., and Henry Margenau, Ph.D. 537 pages, diagrams, 15 × 24 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $4.50.

Such an interest in physics has been taken in recent years that popular and semi-popular books have appeared with the object of interpreting the language of modern physics into more simple language. The result has been to increase the interest so that many readers wish to inquire further, and rather than go to the

formal physics treatise, seek a book that lies between the popular work and the physics text. The authors of the book at hand present it with a view to satisfying those needs. The fundamental problems of physics are approached from a philosophical point of view, first questioning and answering why, then treating methods of physical description and the construction of physical theories.

From the outset, this is followed. Before the reader has progressed through the first three or four pages, on the meaning of a physical theory, curiosity is fired and interest is held. Because the whole of classical physics is based on the concepts of space and time, this is discussed in the second part of the book, in the order first of general concepts followed by physical concepts. Referring back to the construction of physical theories, mechanics or the science of motion is studied, stress being laid on the various descriptions of motion and on an analysis of the logical content of mechanics as perhaps the most important illustration of the construction of a physical theory.

The concept of probability is treated in some detail, a clear outline being given on the conditions under which the special domains of physics that probability analysis as a mathematical technique is limited. A special study is made, in the part of the book on the statistical point of view, of those physical theories which permit an application of probability reasoning. The physics of continua, the electron theory, relativity, and quantum mechanics are all given like attention. The book closes with a chapter on the problem of causality, wherein an attempt is made to appraise the status of the question objectively.

The book is not a text and from the above brief review it can be seen that it lacks completeness in subject matter. The selection of the topics, however, adequately reflects the basic structure of physical thought. It is obvious that a treatment of this kind can not entirely escape the use of mathematics and the requirement of proper background of the reader in physics. With a fair portion of both, and a serious intent for broadening one's perspective, this book should prove invaluable. It is a modern presentation of modern thought.

R. H. OPPERMANN.

ALTERNATING-CURRENT MACHINES, by A. F. Puchstein and T. C. Lloyd. 582 pages, diagrams, tables, 15 × 24 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $5.00.

This new textbook is the result of an endeavor to present the subject matter in a simple, well defined arrangement; the reason being, according to the authors, that students having limited time for study may omit certain parts of the text and yet have available in the text a complete treatment that can be referred to at a later time. Proper arrangement allows this to be done, and examination of this book reveals that it should meet these needs and in addition enhance its value by making a clearer understanding.

The subject matter starts with that usually encountered in schools after a thorough grounding of alternating currents is acquired. It includes alternating current generators, transformers, induction and synchronous motors, synchronous converters, and mercury arc rectifiers. Series motors and repulsion motors are given special treatment and a bibliography pertaining to small motors or to general motor theory as allied to small motors is appended. Each subject is treated in somewhat the order of (1) construction, (2) discussion of operating

characteristics, (3) calculation of operating characteristics from tests, (4) discussions and analyses of various related phenomena. At the beginning of each chapter there is a chapter outline, giving the order and arrangement of the treatment in it—a very helpful feature especially when it is required to refer back sometime later.

Not only do the authors make use of the method of solving problems in order to impress the workability of knowledge given in the text, but at the end of the book, exercise problems are given covering the subject matter in each chapter. Throughout the book references to works of others in papers and reports are noted at the bottom of the page. An index of such authors appears at the end of the book, together with a general subject index.

Often a great many engineers, in practice after graduation have recourse to their old college texts for the purpose of refreshing their minds on a particular theory of derivation of a formulæ. Because the art of electrical engineering is progressing at a rapid pace, it is now necessary to take heed of a new text, modern, complete and simply arranged. This book can be recommended.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Stars and Telescopes, by James Stokley, 319 pages, illustrations, plates, tables, 15 × 22.5 cms. New York and London, Harper & Brothers, 1936. Price $3.00.

Physical Aspects of Organic Chemistry, by William A. Waters, with an introduction by Prof. T. Martin Lowry, 501 pages, diagrams, tables, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., 1936. Price $9.50.

A Systematic Handbook of Volumetric Analysis, by Francis Sutton, 12th edition, 631 pages, diagrams, tables, 14 × 22 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1935. Price $10.00.

Mathematics of Modern Engineering, Vol. 1, by Robert E. Doherty and Ernest G. Keller, 314 pages, diagrams, 15 × 23.5 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $3.50.

The Physical World, by Louis M. Heil, 566 pages, illustrations, 14.5 × 22 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1936. Price $2.75.

Fun with Electricity, by A. Frederick Collins, 238 pages, illustrations, 13 × 19.5 cms. New York and London, D. Appleton-Century Company, 1936. Price $2.00.

National Bureau of Standards, Research Paper RP857, An Absolute Determination of the Ohm, by Harvey L. Curtis, Charles Moon and C. Matilda Sparks. 82 pages, plates, tables, 15 × 23 cms. Washington, Government, 1936.

U. S. Coast and Geodetic Survey, Serial No. 584, Azimuths from Plane Coordinates, by Oscar S. Adams, 14 pages, 15 × 23 cms. Washington, Government, 1936.

National Advisory Committee for Aeronautics, Twenty-first Annual Report, 1935, 44 pages, 23 × 29 cms. Technical Notes, No. 554, Circular Motion of Bodies of Revolution, by Carl Kaplan, 17 pages, tables, diagrams. No. 555, Piloting Technique for Recovery from Spins, by W. H. McAvoy, 7 pages. No. 556, Further Measurements of Normal accelerations on Racing Airplanes, by N. F. Scudder and H. W. Kirschbaum, 3 pages, tables. 3 pamphlets, 20 × 26.5 cms. Washington, Committee, 1936.

CURRENT TOPICS.

Purifying Argon for Filling Incandescent Lamps.—ROBERT P. MORAN in *Industrial Gas*, Vol. 14, No. 6, relates how this is done. Argon as a filler for lamps has taken the place of nitrogen as it has a light transmission value of 12 per cent. better than nitrogen. Because of the cheapness of nitrogen it is still used as a flushing agent to drive out oxygen or other undesirable occupants from the lamp bulb prior to filling it with argon. Impurities, with the exception of small amounts of nitrogen, may give rise to conditions which would result in a product unfit for the trade. The purifying installation in the plant of the Penna. Illuminating Corp., where Keystone Lamps are made, consists of passing commercial nitrogen or argon from shipping cylinders through a pressure reducing valve into a system of 6 stages connected in series under 15 lb. per sq. in. pressure. The stages are (1) soda lime, (2) phosphoric anhydrid, (3) copper chips, (4) copper oxide, (5) soda lime, (6) phosphoric anhydrid. Each stage is made up of a cylindrical container 4 in. in diameter by 24 in. high, sealed at both ends. Stages 1 and 2 are at room temperature, 3 and 4 are immersed in a gas fired unit and operate at 932 deg. F., and 5 and 6 are at room temperature. The gas fired unit is a vertical steel cylinder lined with firebrick. Premixed city gas and air are directed tangentially in a neatly formed combustion chamber resulting in a uniform distribution of heat. The heater has no temperature control, this being accomplished manually within plus or minus 68 degrees allowable variation. This purifying plant can supply nitrogen and argon for 15,000 lamps in 8 hours.

R. H. O.

Moving a Concrete Highway with Air.—ALLEN S. PARK in the December number of *Compressed Air* describes a procedure that is attracting widespread interest. New Jersey Highway No. 26 near New Brunswick provides four undivided travel lanes. Because of the frequency of accidents it was decided to separate the north-bound and south-bound traffic by a 12 ft. space by moving one of the three strips of concrete and adding new concrete along its outer edge so as to make it conform in width to the other lane. Consideration of means for doing this suggested compressed air and the method was devised and developed by Sigvald Johannesson, designing engineer for the N. J. State Highway Dept. The change in

position is effected by inserting a hose in a narrow space next to the strip of concrete to be moved and by inflating the hose with air. As the pressure mounts and the hose expands, the concrete is pushed over slowly, steadily and evenly. By blocking off part of the space thus cleared and repeating the process, the strip of roadway is progressively shoved over until it has been shifted the desired distance. No rollers or other friction reducers are employed. The concrete slab simply slides over the ground surface. From the start of regular operations the scheme functioned smoothly. Approximately 500 ft. of pavement was moved each working day with an expectation of increasing this average. The concrete strip is 14½ ft. wide and has transverse expansion joints at intervals of 35 ft. The established procedure called for moving from 12 to 14 of these slabs at a time. The concrete is 9 in. thick and reinforced. Each slab weighs about 30 tons, the aggregate load being in the neighborhood of 400 tons.

R. H. O.

Acid and Permeability Tests of Cement Pipe.—(*Engineering News Record*, Vol. 115, No. 26.) Acid corrosion and permeability tests of precast 1 : 2 cement-mortar pipe by Danish engineers have led to a number of conclusions of practical interest. As reported by E. SUENSON in a bulletin of Ingeniorvidenskabelige Skrifter the study was organized by a joint committee of the Institute of Civil Engineers of Denmark and the Danish Cement Products Association. The committee believes that the tests have proved that it is feasible to produce a cement-mortar pipe that will permanently resist the corrosive action of aqueous solutions of carbonic acid and other acids that occur in soils and in sewage. Portland cement mortar pipe lengths with 8 to 10 per cent. water content withstood the continuous flow of acid water at a head of 6.6 ft. for 3¼ years, suffering only an interior erosion of 1/32 in. The acid water contained 35 to 535 milligrams per liter of free carbonic acid and up to 135 milligrams per liter of aggressive carbonic acid, also about 240 milligrams per liter of bicarbonate carbonic acid. Water curing insured tight moulding even in pipes of the driest mixes, but it becomes unnecessary when sufficient mixing water is used. Tar and asphalt coatings did not prove advantageous. Tests of portland cement mortar bars, exposed to lactic, carbonic and hydrochloric acids in concentrations of the order 0 : 1 to 0 : 3 normal, showed that it was immaterial whether the first week's curing took place in water or in very damp air, and that the mortar may lose 30 per cent. of its strength when thoroughly permeated with water. It has also been proved experimentally that temperature variations

affect the watertightness of mortar principally through the formation or dissolution of gas bubbles in the water.

R. H. O.

Fog-Piercing Lights.—(*The Pennsylvania Engineer*, Vol. 1, No. 2.) GJON MILI of the Westinghouse Lamp Co. before a joint meeting of the American Physical and Optical Society of America stated that for years research engineers have unsuccessfully sought a new source of color for light that would penetrate fog at a distance safe for aerial and marine navigation. Only recently, however, have engineers thought to increase the brightness of marine signal lamps by operating the lamps over-voltage and utilizing reflectors and lenses to intensify the candle power of light beams. In a daytime fog of medium density, or one in which an object may be seen at approximately 400 ft., marine signals with a 50 candlepower lamp have a visibility range of about 800 ft. In a properly designed reflector or lens the same lamp burned over-voltage could produce as high as 500,000 candlepower. It would be visible three times farther than the 50 candlepower source. Over-voltage operation of an incandescent lamp is the application of a higher voltage than necessary to produce ample light over the usual average life of 1000 hours. The reduction in lamp life through over-voltage operation of signal lamps during a fog could be offset by burning them under-voltage during clear weather. At night the contrast of darkness would double the range of visibility. With possible visibility of about one mile at night in medium fogs, fewer liners and river craft would have to stand by because of night time fogs. The method of stepping up voltage need not be confined to fixed signals such as those operated from utility power lines. Some means might be worked out to equip light buoys, that operate from batteries, with devices to step up voltage in extremely thick weather.

R. H. O.

The Electrical Attainment of Silence.—As an appropriate ending to his paper "Television—An Engineering Catalyzator," ANDREW W. CRUSE, Chief, Electrical Division, Bureau of Foreign and Domestic Commerce, predicted a future component of Acoustical Engineering, that of Silence Engineering. He pointed out that many thousands of dollars are now being expended upon rubber shoes for horses and rubber tires for milk wagons but until sound mufflers are developed for dogs, cats and birds, absolute zero noise level can never be realized unless corrective rather than preventive methods are employed. It is not beyond the realm of theoretical technical possibility to utilize television in the "sound conditioning"

of dwellings which may some day become as common as "air conditioning." This would be accomplished by placing microphones around a room each feeding into an amplifier and thereby immediately producing a sound track on the retina of an iconoscope which as scanned would actuate an oscillator in such a fashion as to produce an out-of-phase frequency on the same level dampening the original actuating sound or noise.

The author urges careful contemplation of such a proposition. Silence so absolute, a pin drop could not be heard. Silent machinery without sacrificing mechanical efficiency, silent hospital rooms with windows open, silent gun fire, silence that might extend to even the conference rooms and lecture halls. What a refined instrument of torture such a "silence" room would make. An inmate could hear absolutely nothing, not even himself.

C.

Explosive Limits of Ethylene Gas.—The growing use of ethylene gas in agriculture has led the U. S. Department of Agriculture to issue the warning that this gas is a dangerous explosive under certain conditions. Three per cent. of ethylene mixed with air is the minimum quantity necessary to produce an explosion. Fortunately, considerably lower concentrations are sufficient for most treating purposes and little danger should result if reliable gas measuring devices are used to control the quantities of ethylene mixed with the air.

Thus, only one-tenth of one per cent. is required to loosen the "stick-tight" green hulls of walnuts—any more is undesirable. Ethylene gas is also used to bleach the green color of oranges and lemons.

C.

Germany Covers News Events with Television.—In a paper presented before the combined Engineering Societies of Schenectady, New York, ANDREW W. CRUSE described a very interesting piece of equipment developed by the Broadcasting Company of Germany. It is termed a Television truck and is used to cover news events. The equipment consists of a low-powered ultra-short-wave transmitter for both sound and television using the intermediate film method. The interval of delay between the taking of the picture by the camera mounted on top of the truck and the time when that picture has been televised is approximately 90 seconds. It is reported that the Broadcasting Company engineers believe the high speed with which it is necessary to develop and fix the film does not

give a satisfactory sound track and are consequently preparing to record the sound by the steel tape method developed by the Lorenz Company.

C.

Publication of Scientific Journals by Microphotography.—Thus reads the title of a brief section in a comprehensive report by the Documentation Division of Science Service. As a possibility for the future, this organization is experimenting with the placing of a photographic image of an 8½ in. × 11 in. letter-sized typescript upon an area 1/4 inch or less in height. This is believed to be a technical possibility. A piece of film the size of a library card, 3 in. × 5 in. would then carry 150 to 200 pages of typescript, the equivalent of the ordinary issue of a sizable scientific journal. With the development of a suitable reading machine for these microphotographs, it would be possible to provide a subscriber with such a machine on a rental or time-payment basis together with the monthly issues of the film carrying the images of the material being published.

C.

Effect of Sulfur Dioxide on Wheat Development.—ROBERT E. SWAIN and ARTHUR B. JOHNSON (*Industrial and Engineering Chemistry*, Vol. 28, No. 1). Much discussion has centered on plant life injury due to the production and discharge of sulfur dioxide from metallurgical and other industrial operations. Observations on the effects produced revealed many inconsistencies due to innumerable variables. The authors describe an investigation setting aside or controling the many variables of soil, climate, and insect action which have often made open field studies uncertain. Plants were grown in glass cabinets from selected seeds of a pure line, nourished from germination to the harvest by clear solutions of inorganic plant foods, and kept throughout the entire period of growth under controlled conditions of artifical light and temperature in a gentle stream of air. Sulfur dioxide was added in carefully regulated amounts continuously to the air stream during the daily fumigation period. The results of this study indicate that wheat plants grown under favorable conditions will tolerate an exposure to sulfur dioxide of several hours daily in concentrations below those at which typical foliar markings are produced without showing any signs of injurious actions in their general appearance, in their rate of growth, or in the dry weight of tissue which they develop. It is pointed out that under conditions much less favorable to rapid

growth and development, which may often prevail in the open field, such as a serious lack of soil moisture or plant food, it is conceivable that the tolerance of the plant for sulfur dioxide would be altered and this substance become a possible contributing agent to an unflourishing condition.

R. H. O.

Cleaning Gasoline Pipe Line.—(*Oil and Gas Journal*, Vol. 34, No. 34.) According to "Our Sun," the house organ of the Sun Oil Co., trouble was not anticipated in 1930 by the Susquehanna Pipe Line Co. when their gasoline pipe line was laid, but by the middle of 1935 the capacity of the line was reduced from 15,000 to 12,000 bbls. per day. There are two branches of the line from Marcus Hook, Pa., one to Syracuse, N. Y., and the other to Cleveland, Ohio. The work of cleaning it began with taking up portions containing sharp bends and check valves and removing obstructions. Gasoline was removed from the section of the line to be cleaned by pumping through a water "plug." The last phase of the cleaning operation employed two types of scrapers, a knife and brush type of scraper. Both were propelled or pushed through the line by the water pressure exerted by the pumps. The scrapers scrape the walls of the pipe free of scale. They travel through the pipe at a speed of 2 to 3 miles per hour. When a scraper becomes stuck in the pipe, a "bumper" scraper is sent through to aid the stuck scraper to move forward. The material removed by the scrapers was pushed ahead and finally discharged. Many foreign objects were removed including rocks, pieces of wood, tool parts, scraper parts, welding icicles, a 10 ft. length of 2 × 4 lumber and a shorter piece of 2 × 4 entangled in a mass of burlap. The scale formed upon the inside of gasoline pipe lines is usually in the form of small pieces of iron oxide.

R. H. O.

Bridge Railings Removable in Case of Floods.—J. W. BERETTS. (*Engineering News Record*, Vol. 116, No. 4.) Repair of flood damage to the international highway bridge over the Rio Grande between Laredo, Texas, and Nuevo Laredo, Tamaulipas, Mexico has resulted in the installation of a railing that is easily detachable and thus may be removed on flood warnings, to eliminate an important obstruction to drift and current. Two past floods have overtopped this bridge and observations augmented by hydraulic calculations indicated that the old railing, of heavy concrete construction, offered as much as 50 per cent. of the total resistance of the structure con-

sisting of five 150 ft. deck spandrel arch spans, flanked on the American end by a 61 ft. deck beam span and on the Mexican end by a similar span 50 ft. long. The roadway is 28 ft. wide and is flanked by two cantilever sidewalks 5½ ft. wide. Structural aluminum railing was decided upon. It consists of 173 sections, averaging 10 ft. in length and 46 in. in height. They are fitted into galvanized steel bracket plates permanently fastened to the bridge.

R. H. O.

Radio Controls Snow Plows and Cars.—LACEY V. MURROW. (*Construction Methods*, January 1936.) During the winter of 1933–34 radio equipment was installed at fixed stations, by the Department of Highways of the State of Washington, at the summit of Snoqualmie Pass, at Crystal Creek Camp in Chinook Pass, and in the District Headquarters office at Seattle. Transmitting and receiving sets were also installed in two snow plows operating in Snoqualmie Pass. After a few weeks operation, this method of communication proved so advantageous that a network was installed. At the present time the setup consists of 17 fixed stations 8 of which are of 50 watt capacity and 9 of 10 watt capacity. The mobile stations operated are 12 in number, each equipped with transmitting and receiving sets of 10 watt capacity. In addition passenger business cars of district officials have been equipped with receiving sets. The operation of this radio communication system is carried on at practically no expense involving special operators. Installations are made in shops where clerks and operators of mobile units are encouraged to become licensed radio operators, which is necessary under Federal laws.

R. H. O.

New Method for Welding Together Ferrous Metals by Application of Heat and Pressure.—LEONARD C. GRIMSHAW. (*Metals Technology*, Vol. 3, No. 1.) The bonding of two dissimilar ferrous metals and making use of both has several advantages; the physical properties of one steel may supplement those of another; an expensive steel may be backed by a less expensive one; a useful steel may be backed by a steel that is easier to machine. There are two methods in use that result in good bonds; the casting method and the heat-pressure method. The former has been used for more than 74 years, but the latter was announced in the technical literature in 1931 although no details of it were published. The author describes the commercial uses and applications of this heat-pressure method, developed by P. A. E. Armstrong. The ferrous alloy is cleaned so as to free it from all oxide film and has plated upon its

surface a few thousandths of an inch of electrolytic iron. Any subsequent heating to a good red heat will start diffusion between the ferrous alloy and the electrolytic iron. The iron-plated ferrous alloy may be welded to a piece of soft iron, or to any other ferrous alloy similarly iron-plated, by placing the two prepared faces in contact, heating to a good red heat, and applying pressure. If, during this heating, precautions are taken to guard against scaling of the two prepared surfaces, a weld will be produced that is oxide free. The weld has taken place between two clean iron surfaces, each held by diffusion to its ferrous-alloy backing. This weld is strengthened by each subsequent heating, until elements from the ferrous alloys have diffused entirely through the electrolytic-iron weld zone. Properly prepared and assembled composite billets welded by this method are free from non-metallic material in the welded zone, and the welded materials fuse one into the other as a graduated alloy.

R. H. O.

Wood No Longer Fuel.—(*Safety Engineering*, Vol. 71, No. 1.) A method of preventing large fire losses is to limit the amount of available fuel at the point of origin of the fire. This means that the use of fireproofed wood for floors and interior trim would be an effective method of combating loss. A recent contribution of science is fireproofed lumber of red oak and maple. The successful fireproofing of this lumber is effected by a method not unlike that used in the treatment of railroad ties with creosote for protection against decay, except that incombustible salts are used, a process invented by Dr. W. Whitmore and Ernest F. Hartman. The Underwriters Laboratories, after making severe tests of this treated wood, state that it is practically noncombustible and nonflammable. Whole floors of the lumber, and others of untreated lumber, were subjected to a roaring inferno in gas fired furnaces especially designed for such work. The fireproofed floors came from the furnace at the completion of the tests blackened and charred on the exposed surface but intact and otherwise sound, having successfully stood as a barrier against the fire and prevented its passage. The untreated floors did not fare so well. Properties of the treated lumber other than its fire resisting qualities were also investigated. Its workability was found to be equal in every way to that of untreated lumber. Its ability to take paint and varnish is not altered, its appearance is unchanged and its weight is only slightly greater than that of untreated lumber. Under fire attack it emits no injurious fumes and it causes no undue corrosion of nails or screws.

R. H. O.

"Exploroscope"—For the Interior Inspection of Gas Mains. —W. M. HENDERSON. (*American Gas Association Monthly*, Vol. XVIII, No. 2.) A new tool for the gas man, that has novelty, utility and simplicity, has been designed and built by T. G. Wallace and R. G. Holman of the research staff of the Los Angeles Gas and Electric Corporation. It has the appearance of a tube, one end of which contains an electric light bulb and the other a microscope eyepiece. The electric light bulb end can be inserted into a gas main under pressure by means of a gate valve and packing gland. The Exploroscope proper consists of three optical units: the standard interchangeable microscope eyepiece, the inverting lens and the objective lens. Each is a combination of two achromatic lenses. The eyepiece slips into a barrel mounting which screws into a brass sleeve forming a telescoping unit for focusing. The electric light bulb is a special Edison Mazda lamp, 10 v., 7.5 amp. and is arranged so that both it and a reflecting prism can change position permitting ocular inspection of the inside pipe walls entirely around the periphery of the pipe. With a camera attachment on the eyepiece end, the instrument permits photographs to be made in more detail than is disclosed to the eye, and by longer exposures a photograph can be taken of interior sections that are actually too far to be seen with the eye.

R. H. O.

The Termite Fire Hazard. C. M. STEGNER. (*Quarterly Journal of the National Fire Protection Association*, Vol. 29, No. 3.) While termites cannot be charged directly with incendiarism their contribution to building fire hazards is by no means imaginary. Termite damage is a most serious problem that has received but little consideration as a fire hazard. A recent illustration of a termite fire hazard that might have caused a $5,000,000 conflagration occurred in a Cincinnati distillery. Evidence of termite infestation resulted in the employment of an exterminating company who used a process consisting of locating all termite nests or points of termite access to the earth and then treating these locations with a poisonous liquid. This liquid was applied from a compressor through a hose, pipe and nozzle under a pressure of 150 lbs. per sq. in. The pipe was inserted into tight-fitting holes drilled in the wood. While working thus in the basement of a building a 200 watt electric lamp on an extension cord fell and broke. The glowing lamp filament started a flame which ran over the saturated wood. A fire alarm was turned in and the two termite exterminators collapsed from inhaling hot fumes. They were rescued however. The Cincinnati fire department soon had the blaze under control.

A subsequent analysis of the exterminating fluid showed a mixture of 85 per cent. kerosene or mineral spirits, 12.5 per cent. ortho-dichlorobenzene and 2.5 per cent. residue. The flash point of the mixture was 115 deg. F. open cup and the temperature of the little or no ventilated basement before the fire was about 70 deg. It is probable that the distillery flash resulted from a fine oil spray retained in the confined basement atmosphere.

R. H. O.

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